Texas A&M Transportation Institute

Improving Aircraft Emissions Inventory Development

FINAL REPORT

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EXECUTIVE SUMMARY

The Texas Commission on Environmental Quality (TCEQ) routinely develops statewide emissions inventories (EI) for all airport source categories in Texas, including aircraft, auxiliary power units (APU), and ground support equipment (GSE). These EIs are needed to fulfill the United States (US) Environmental Protection Agency’s (EPA's) comprehensive three-year cycle Air Emissions Reporting Requirements (AERR) and to support state implementation plan (SIP) development and air quality planning.

The objective of this project is to improve the accuracy and efficiency of airport EI development. The primary focus is on the estimate of aircraft activity, which is a critical element for estimating airport emissions.

The primary accomplishments of this study include:

1. **Automated the data processing and input preparation processes.** This improvement significantly increases the efficiency of preparing the airport EI for all future AERR inventory work.
2. **Explored data sources and methods that can provide robust and accurate activity data.** The Texas Transportation Institute (TTI) study team found that collecting activity data directly from landing facilities is typically the most common approach used to develop an accurate estimate of aircraft activity inputs. However, collecting data from different aviation facilities can sometimes be difficult as the data may not be readily available. Alternative data sources are often used to develop a full set of activity data needed to estimate emissions. The TTI study team reviewed and explored various alternative data sources and identified the data that could improve the estimate of aircraft activity. In addition to the data sources used in the 2020 airport EI (Venugopal & Bibeka, 2021) (henceforth known as the 2020 Airport AERR EI), the TTI team used the Federal Aviation Administration (FAA) registration data to improve the estimate of the fleet mix, Airline Service Quality Performance (ASQP) data to improve the estimate of the fleet mix of air carriers at major commercial airports, The General Aviation and Part 135 Activity Survey (GA survey) data to improve the estimate of General Aviation (GA) and Air Taxi operations.
3. **Improved existing and developed new methodologies to generate the inputs (e.g., aircraft operations and fleet mix) needed by the airport emissions model.** Compared to the 2020 Airport AERR EI, the most important methodological improvement is the newly developed methods to improve the Landing and Take off (LTO) operations of GA and air taxis using GA survey. For

fleet mix estimate, the most important methodological improvement is that this study separates the LTOs into two categories: itinerant and local LTOs, and developed different methods to estimate the fleet mix in each category. The newly developed LTO estimates for commercial, reliever, and TSAP airports are close to those used in the 2020 Airport AERR EI. For the other landing facilities, the newly developed LTO estimates are higher. The newly developed fleet mix has a lower percentage of jet-engine aircraft while a higher percentage of piston-engine aircraft.

4. **Assessed the impact of alternative data sources and improved/new methodologies developed on the airport EI.** Their impacts on the airport EI are mixed in that the emission of some pollutants increases while the emission of others decreases. Given the fact that airport emission is a relatively small contributor when compared to other source category emissions, these changes are not significantly affecting the overall emissions.

Since landing facilities are the best sources to obtain accurate aircraft activity data, for all future EI development the TTI study team will continue to work closely with landing facilities to acquire accurate activity data and fleet mix. However, the improved methods and procedures to estimate aircraft activity, including the resulting activity data sets, developed in this project will be used for scenarios where landing facilities cannot provide the data needed.

For future study, the TTI study team recommend that continuous effort be made to improve the estimation methods and explore the possibility of using data from emerging technologies to improve and validate the estimates of aircraft activity.

1 INTRODUCTION

The TCEQ routinely develops statewide EIs for all airport source categories in Texas, including aircraft, APUs, and GSE. These EIs are needed to fulfill the US EPA's comprehensive three-year cycle AERR and to support SIP development and air quality planning. The primary tool used to develop an airport EI is the FAA's Aviation Environmental Design Tool (AEDT). AEDT dynamically models aircraft performance in space and time to produce fuel burn, emissions, and noise estimates. AEDT can be used for modeling studies ranging in scope from a single flight at an airport to scenarios at the regional, national, and global levels. Versions of AEDT are actively used by the US government for domestic aviation system planning as well as domestic and international aviation environmental policy analyses. To develop an airport EI using AEDT, the following airport-level aircraft activity inputs are needed:

- (LTOs,
- Fleet Mix (i.e., airframe and engine type) of the LTOs,
- Taxi-In and Taxi-Out Times,
- Aircraft APU usage, GSE fleet mix data, and any associated emission control measures (e.g., gate electrification).

To develop these EIs, activity data such as LTO cycles, fleet mix, taxi times, emissions control strategies, and other critical data elements must be obtained directly from airport facilities or open-source data sets, and then processed to develop inputs for the AEDT model. Developing aircraft activity inputs for airports in Texas can be challenging as Texas has more than 2,000 landing facilities[1], which accounts for about 10% of the total landing facilities in the US. Many of the Texas landing facilities primarily serve GA activity [2], which are usually not well-tracked.

To help address this challenge, pre-processing procedures can be developed to more effectively collect and format airport operations and activity data distributions by modes (GA, military, air carrier, etc.), which will improve the efficiency of airport EI development. Additionally, exploring alternate data sources such as those from the Bureau of Transportation Statistics (BTS), FAA, and other open-source data sets will provide a more robust and accurate activity data collection process.

[1] Statistics based on FAA's Airport Master Record (Form 5010)

[2] GA activity are a diverse range of aviation activity including all segments of the aviation industry except commercial carriers and military

1.1 Objective

The purpose of this project is to improve the accuracy and efficiency of airport EI development by:

1. Exploring alternate data sources and methods that can provide more robust and accurate activity data,
2. Improving existing methodologies and developing new ones to generate the inputs (e.g., aircraft operations and fleet mix) needed by the airport emissions model,
3. Assessing the impact of alternative data sources and improved/new methodologies on airport EI.

Various open-source data sets, such as those available from the FAA, and airport-specific data are used to develop the TCEQ's airport EIs. These data sets cannot be directly used in the FAA's AEDT model because of how the FAA tracks and formats the data. A gap exists in which emissions model users, with limited resources and expertise, need to correctly interpret the activity data to accurately use the AEDT model to develop airport emissions estimates. To address these issues, this project will develop pre-processing procedures to automate the development of emissions model-ready input files from various input data sets. These pre-processing procedures will improve the steps involved in developing airport EIs by providing a more efficient method for acquiring recent activity data from airport facilities, shortening the time needed for such efforts. These procedures will also improve the accuracy and consistency of airport EIs by allowing for more customized input and output data from the AEDT model.

1.2 Study Task and Chapter Summary

The study, *Improving Aircraft Emissions Inventory Development*, consists of six tasks. Task 1 is the preparation of the grant activity description (GAD) and quality assurance project plan (QAPP) documents. The TTI study team submits monthly progress reports to the TCEQ project managers (PM) and contract specialists (CS) per Task 2. For Task 3, the study team conducted a literature review to identify and assess various sources for airport activity data sets that can be used to develop airport EIs using the AEDT model. For Task 4, the study team analyzed and evaluated the activity data sets identified and collected from Task 3 to assess the reliability and feasibility of processing the raw data and formatting it into useable AEDT model inputs. The updated airport activity AEDT input files developed during Task 4 were applied in AEDT to estimate EIs which the study team compared to EIs produced in the most recent 2020 airport AERR and trend

EI project (Proposal for Grand Activities [PGA] 582-21-11196-018) in Task 5. Finally, the study team prepared this final report and deliverables for submission to the TCEQ PM and CS per Task 6 requirements.

Task 3 of this study is covered in Chapter 2 (Literature Review) and Chapter 3 (Data Gathering and processing). Chapter 4 (Activity Development) documents the work and findings related to Task 4 of this study. Task 5 of the study is covered in Chapter 5 (Validation) and Chapter 6 (Assessment of Emission Impact). The concluding chapter summarizes the findings of this study and the study team's recommendations for the next steps.

2 LITERATURE REVIEW

This chapter covers the literature review that the TTI study team performed under Task 3 - Literature Review and Airport Activity Data Gathering. The TTI study team focused on reviewing data sources and the methodologies/models that have been used or have the potential to be used in airport EI development. To be concise, the methodologies used in previous airport EI studies sponsored by TECQ are not presented here.

2.1 PRIOR WORK

One of the traditional methods for preparing aircraft activity inputs for AEDT is to collect the data directly from airports using surveys. Such data collection efforts have been undertaken in several previous airport EI studies (Eastern Research Group, Inc. 2019; Venugopal et al. 2020). However, survey efforts to collect activity data directly from airport facilities are often met with the following challenges:

1. The geographic extent and the number of facilities being surveyed.
2. Most of the airports may not have the data requested for EIs. For example, at some small GA landing facilities, aircraft activity is usually not well-tracked.
3. Timely responses from airports are not guaranteed. Previous studies have reported relatively low response rates. Table 1 presents the survey response rate, by airport category, reported in the *Development of the Statewide Aircraft Inventory for 2020* (Venugopal et al. 2020).

Table 1: Summary of Texas Airport Response Rates (Venugopal et al. 2020)

Facility Type	Number of Facilities	Facilities Surveyed	Responses Received	Percent Responded
Commercial Service	26	26	5	19%
Reliever	25	24	6	25%
Military	21	8	1	13%
Other Texas Airport System Plan	233	191	27	14%
Farm/Ranch	465	171	27	16%
Medical	189	25	2	8%
Other Public	100	20	8	40%
Other Private	957	20	7	35%
Total	**2,016**	**485**	**83**	**17%**

As an alternative, the aircraft activity inputs can be developed from regularly published data sources. TCEQ and TTI made a significant effort to identify data sources for developing aircraft activity inputs for AEDT, which were needed to fill data gaps from the surveys during the previous studies (Venugopal et al. 2020).

2.2 Review of Methodologies

1. The first study assessed by the TTI team (Coralie Cooper et al. 2016) provided recommendations on reasonably accurate and low-cost methods to inventory airport Green House Gas (GHG) emissions. The study is mainly focused on how individual airports should develop GHG EIs. The major findings of the study are summarized as follows:

    - The study identified three models to estimate GHG emissions: AEDT, the Airport Carbon Emissions Reporting Tool (ACERT) (Airports Council International 2021), and the Federal Energy Management Program (FEMP) tool. All three tools would require significant input data collection efforts. Interviews conducted during the study found that it could be challenging for an airport to collect its airport data. This finding may partially explain the low response rate of the survey approach and highlights the importance of developing the activity inputs to airport EIs using other data sources.
    - The study found that AEDT is a reliable and effective way to estimate aircraft GHG emissions as it is continually updated, providing robust and up-to-date GHG estimates based on the current aircraft and engine fleet, as well as current airport characteristics. In contrast, both ACERT and FEMP are free. The ACERT tool is designed for airports and is thus more tailored than FEMP. ACERT provides a means to calculate airport-specific (e.g., aircraft emissions), whereas FEMP does not. However, FEMP estimates a range of GHG emissions, while ACERT focuses on CO_2 and can be used to develop GHG management on a voluntary (non-regulatory) basis. For airports that do not have access to aircraft emissions estimated with AEDT or another model, the study recommends that it may be easiest and least expensive to use ACERT to calculate aircraft GHG emissions.

    The second study assessed by the TTI team (Planning and Environmental Affairs Department 2020) developed a GHG EI for San Diego International Airport. The EI includes GHG emissions from three source scopes. The first one is airport authority-owned and operated mobile combustion sources such as a fleet of vehicles, equipment, and shuttles that utilize gasoline, diesel, and renewable natural gas. The second one is the authority-owned facilities and infrastructure such as terminal buildings and administrative offices. All other emission sources are included in the third type, including aircraft LTOs, GSE, rental car centers, surface access by passengers, and the air traffic control tower. The study suggests that emissions from the third scope account for more than 98% of the total emissions. Figure 1 shows the distribution of the emissions among activity of the third scope. The aircraft LTOs, surface access by passengers, and tenant staff/visitors vehicles account for more than 93% of the total emissions in this category. The emissions by APU only account for 1.1%. This study also considers specific emissions reduction policies such as using landside power and preconditioned air at gates and cargo facilities and hangars, electric/alternative fuel-powered ground vehicles, and reducing aircraft movements. However, the study did not specify the model used to estimate the GHG emissions (the TTI infers that ACERT was used). Other similar GHG inventory studies include (Los Angeles World Airports 2014; The Environmental Consulting Group 2009; Los Angeles World Airports 2019). Though these studies considered comprehensive emission sources, it was conducted by the airport authority that has access to the necessary data. Thus, it is questionable whether the method in the study can be used to develop EIs for all airports in Texas.

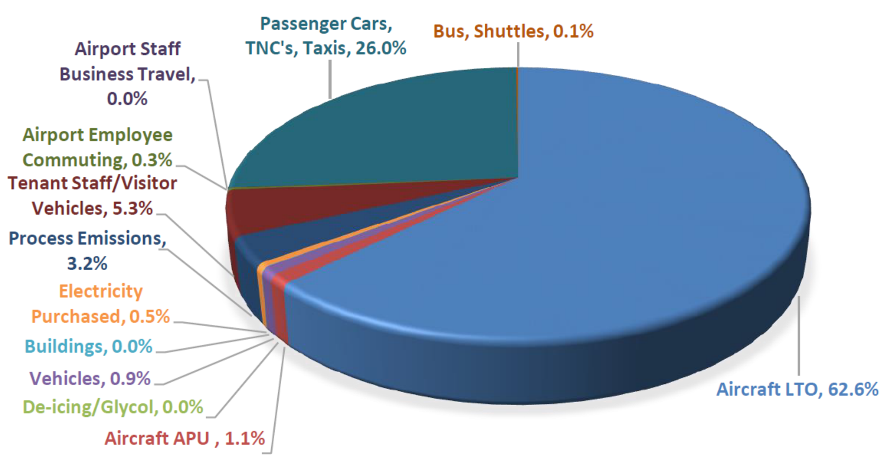

Figure 1: Distribution of emissions among activity in the third source type

2. The third study assessed by the TTI team (Brian et al. 2009) developed a guidebook on preparing airport GHG EIs. Three methods are proposed to estimate aircraft GHG EIs:

- Method 1: Use fuel sales data at airports to calculate total emissions for all departure flights. However, this approach cannot estimate the GHG emissions during LTO and cruise separately. Moreover, the fuel sales data at airports could be difficult to obtain.
- Method 2: Use fuel sales data in combination with methods or models to separately calculate LTO emissions. This method not only requires fuel sales data but also input data for other methods/models which could be more difficult to implement.
- Method 3: Use models capable of calculating emissions associated with all modes of flight. Particularly, the study suggests that AEDT could be one of the preferred models.

3. The fourth study assessed by the TTI team (Norton, 2014) produced an EI from jet-A fuel for three airports (i.e., San Francisco International Airport, Oakland International Airport, and Norman Y. Mineta San Jose International Airport) of the San Francisco Bay Area using FAA's Emissions and Dispersion Modeling System (EDMS). The operational data are from the FAA's Traffic Flow Management Counts from 2011 to 2013. In this study, the method of the Intergovernmental Panel on Climate Change Good Practice and Uncertainty Management in National Greenhouse Gas Inventories was used. GHG emission inventories were examined, including GHG, methane (CH_4), and Nitrous oxide (N_2O). GHG is estimated by method 2 of the study by (Brian et al. 2009). CH_4 and N_2O were estimated by using their amount of emissions per gallon of jet-A fuel.

4. In the fifth study assessed by the TTI team (KB Environmental Sciences, Inc., 2013), three general alternative approaches to developing the airport EI for state implementation plans are proposed: Basic approach, Intermediate approach, and advanced approach:

   - **Basic Approach** - the simplest and requires the least amount of airport-specific data. The approach requires the same basic aircraft operations data as the other two approaches but uses generalized aircraft fleet mix data and conservative assumptions regarding aircraft engines. It also relies on the use of AEDT/ EDMS default assumptions on taxi and delay times, APU usage, and GSE fleet mix and use times. It provides a conservatively high estimate of an airport's EI and is best suited for non-hub commercial and GA airports with typical airfield operating characteristics and less than 100,000 annual operations. The study also developed an airport emission estimator tool to facilitate the preparation of the EI.

- **Intermediate Approach** - a transitional between the other two approaches. This approach produces results with a higher level of accuracy than the basic approach while requiring fewer input data than the advanced approach. Compared with the basic approach, the intermediate approach relies on default databases in the AEDT/EDMS for aircraft engines, APU, and GSE. This approach is suitable for large GA and small-to-medium-hub commercial airports located in moderate nonattainment and maintenance areas.
- **Advanced Approach** - produces an EI with the highest level of airport specificity and is therefore considered to be the most accurate. Rather than relying on default input parameters, this approach requires the greatest levels of expertise and effort by the preparer and is the most data-intensive. Additional simulation software may also be needed to generate the required data. This approach is best suited for large-hub commercial airports but can also be applied to small-to medium-hub and GA airports where advanced levels of accuracy and airport specificity are desired. This approach is also most appropriate for airports located in nonattainment areas with serious-to-extreme severity designations.

5. In the sixth study assessed by the TTI team, (Heiken, 2015) a tool was developed to make a Pb inventory of aviation gasoline containing tetraethyl lead. At the basic level, the EPA's triennial national emissions inventory (NEI) is used in the study. Facility-specific airport activity data such as those found in the Terminal Area Forecast (TAF) or Air Traffic Activity Data System (ATADS) datasets were used to develop inputs. For information on aircraft fleets, piston fuel rates, time-in-mode data, and aviation fuel usage users can choose one of three types of data: data directly collected by airports, data developed in the study, or FAA/EPA default data. The operational mode can be taken among facility-specific input, input developed in the study, FAA/EPA default with run-up included, or FAA/EPA default. By enhancing the flexibility of data, as above, this development allows inventories to be based on the enhanced inventory methodology developed as part of the study and makes it possible to use more specific data. Overall, the author recommends using facility-specific data instead of national average data.

6. In the seventh study assessed by the TTI team (Lu, et al., 2018), an estimation model for LTO activity emissions was devloped. To estimate emissions, emission factors by airplane type developed in Manual (Environmental Protection

Department of China, 2014) and Zhang et al. (Lijun, Zheng, Yin, Kang, & Zhong, 2010) were used. The number of LTOs per day by airplane type was collected from April 2015 to April 2016 from the website and the annual LTO is calculated. This study shows a new way to collect LTO records. However, the method cannot be applied to airports that do not make the LTO information available on their website (e.g., small GA airports).

7. In the eighth study assessed by the TTI team (Graver, Rutherford, & Zheng, 2020), the amounts of CO_2 emissions by source, activity, and passenger types in 2013, 2018, and 2019 were analyzed. The global Aviation Carbon Assessment model is used to estimate CO_2 emissions. In calculating fuel burn, software Piano 5 aircraft files are used considering the weight of flight, passengers, and freight. Operation data was from the Official Airline Guide (OAG), International Civil Aviation Organization, individual airlines, and the Piano aircraft emissions modeling software. Specifically, LTO and fleet mix data were from OAG, while data about freight air carriers (DHL, FedEx, and UPS) was from US DOT. Taxi time is set as 25 minutes considering the data of US DOT -.

8. In the ninth study assessed by the TTI team, Washington State Department of Ecology developed a comprehensive EI including all source categories for Washington State (Farren, Tom, and Sally 2020). The EI for aircraft activity is directly acquired from the EPA’s 2017 NEI (EPA 2020a).

Based on the literature review, the TTI study team confirmed that, although aircraft activity is a critical element for estimating airport emissions, the aircraft activity data needed is often challenging to obtain. Though stakeholders at landing facilities may keep track of some aircraft activity, collecting data from different stakeholders can sometimes be difficult. Therefore, it is not always practical to collect the activity data needed directly from a large number of landing facilities. As a result, estimation methods are often developed to estimate the activity data needed.

3 DATA GATHERING AND PROCESSING

This chapter documents further data review and assessment work done by TTI as part of a broad effort to improve the process of preparing aircraft activity inputs for AEDT. Most of the data sources/sets that have been reviewed in the previous studies (such as ERG 2019, Venugopal et al. 2020) are also included in this review and assessment. However, the work here differs from the work in previous studies in the following aspects:

1) A review of methodologies/models is used to develop airport EI.
2) Additional data sources/sets are identified that could be used to improve aircraft activity development. For example, this study found that the Automatic Dependent Surveillance-Broadcast (ADS-B) data has the potential to provide better aircraft activity in Texas due to its high level of coverage. In addition, several other data sets could be used to estimate GA activity.
3) This study assessed the pros and cons of each data source/set. This is crucial to select the appropriate data sets (e.g., to capture the temporal variation of the activity in airport EIs [ERG Inc 2019]), evaluate their impact on EIs, and identify potential areas for future improvements. For example, the assessment in this study suggests that FAA's Airport Master Record (AMR) could have more applications in aircraft activity development than was assumed in the previous study.

3.1 DATA SOURCES REVIEWED

This subchapter summarizes the data sources reviewed and assessed. The presentation of data sources is in the following order:

- BTS,
- FAA,
- US EPA,
- Energy Information Administration (EIA), and
- Other sources, most of which require purchasing data.

For each data assessment, TTI introduces the data and how to access it, presents example records, assesses the pros and cons of the data for use in developing activity inputs for AEDT, and makes recommendations on how to use the data.

3.1.1 Bureau of Transportation Statistics

This section summarizes the data sources from BTS.

3.1.1.1 T-100 Segment Data

The BTS collects and publishes monthly domestic and international segment data by the US and foreign air carriers (T-100 segment data). Specifically, the data contains non-stop segment flight information such as flight origin and destination airports and aircraft type.

The data is available for download for each month of a year via the website: https://www.transtats.bts.gov/DL_SelectFields.aspx?gnoyr_VQ=FMG&QO_fu146_anzr=Nv4+Pn44vr45

Table 2 presents sample T-100 records with the departure airports in Texas in July 2019. The first record in the table shows that there are 522 flights performed with aircraft type 612 (Boeing 737-700) from airports HOU to DAL this month.

Table 2: T-100 Segment Records

Departures Performed	Payload	Distance	Origin	Destination	Aircraft Type*
522	18061200	239	HOU	DAL	612
510	17646000	239	DAL	HOU	612
360	18161000	1235	DFW	LAX	699
298	15403600	936	DFW	CLT	699
280	10908140	731	DFW	ATL	694
279	9653400	189	DAL	AUS	612
278	9618800	247	DAL	SAT	612
274	9480400	247	SAT	DAL	612
253	10047600	1205	DFW	SNA	614
245	12373700	1464	DFW	SFO	699

*A lookup table is provided by the BTS to link the aircraft type code to the actual aircraft type

The advantages of the T-100 segment data are as follows:

1) The aircraft type information in the data can be mapped to the airframe and engine type in the AEDT. Thus, it not only contains the LTO data (i.e., the departures) but also the fleet mix information associated with the LTO data. Due to this, EPA developed the LTO data and associated fleet mix for states, using T-100 data, as one of the primary sources (EPA 2020b).

2) Since the data is provided monthly, the seasonality of the aviation activity can be captured in the data provided by BTS

The main disadvantage of using the T-100 segment data for developing aircraft activity is that the data has limited coverage. Since the T-100 segment data are reported by carriers, it primarily contains commercial flight and air taxi flight information. In other words, the data contains little or no information about GA flights. In the Texas airport EI developed for TCEQ by TTI (Madhusudhan et al. 2021), GA accounts for a large portion of the LTOs and therefore emissions. Table 3, Table 4, and Table 5 present the LTOs and emissions by operation type for Houston-Galveston-Brazoria (HGB), Dallas-Fort Worth (DFW), and San Antonio areas, respectively. GA LTOs account for more than 60% of the total LTOs in each area and a significant portion of VOC, PM, CO, and Pb emissions.

Table 3: LTOs and Emissions by Operation Type for the HGB area

HGB	LTO	VOC	NO_X	CO	PM_{10}	$PM_{2.5}$	SO_2	CO_2	Pb
Commercial	35.1%	34.5%	77.7%	29.5%	55.8%	55.8%	74.2%	74.2%	9.0%
Air taxi	2.2%	3.7%	4.9%	1.3%	5.5%	5.5%	3.7%	3.7%	0.0%
GA	60.3%	58.3%	15.4%	67.3%	36.9%	36.9%	19.8%	19.9%	90.1%
Military	2.4%	3.5%	2.0%	1.9%	1.8%	1.8%	2.2%	2.2%	0.9%

Table 4: LTOs and Emissions by Operation Type for the DFW Area

DFW	LTO	VOC	NO_X	CO	PM_{10}	$PM_{2.5}$	SO_2	CO_2	Pb
Commercial	30.9%	41.0%	76.8%	27.2%	63.2%	63.2%	73.6%	73.6%	5.1%
Air Taxi	2.4%	3.5%	5.8%	1.2%	6.6%	6.6%	4.4%	4.4%	0.0%
GA	63.3%	49.9%	14.4%	68.1%	27.4%	27.4%	18.4%	18.4%	93.5%
Military	3.4%	5.6%	3.1%	3.6%	2.8%	2.8%	3.7%	3.7%	1.4%

Table 5: LTOs and Emissions by Operation Type for the San Antonio Area

SAN	LTO	VOC	NO_X	CO	PM_{10}	$PM_{2.5}$	SO_2	CO_2	Pb
Commercial	31.0%	37.7%	83.4%	27.5%	59.6%	59.6%	76.4%	76.4%	10.8%
Air Taxi	1.5%	2.2%	3.6%	0.8%	4.8%	4.8%	3.1%	3.2%	0.0%
GA	62.0%	55.6%	10.0%	69.3%	32.7%	32.7%	16.2%	16.3%	88.4%
Military	5.5%	4.6%	3.0%	2.4%	2.8%	2.8%	4.2%	4.2%	0.8%

Though this data set is used by the EPA to create the LTOs, TTI may caution against using T-100 segment data as a primary data source to develop airport activity for the following reasons:

1) There are other data sets (e.g., TAF and Traffic Flow Management System Count introduced in the following section) that can provide comparable LTO information, with the added benefit of covering more airports.
2) As most of the commercial flights and air taxi flights conducted by carriers are performed under Instrument Flight Rules[3] (IFR), the fleet mix information in the T-100 segment data could be covered by other data sets reviewed in this study.

TTI may consider using this data set secondarily to conduct, for example, validation and quality assurance and quality control (QAQC).

3.1.1.2 Airline Service Quality Performance

ASQP provides air carrier service quality information. The US certificated air carriers within 1% or more of the total domestic scheduled service passenger revenues (about 17 carriers) are required to report data for flights involving any airport in the 48 contiguous states accounting for 1% or more of the domestic scheduled service passenger enplanements. Some of the data elements included are gate departure, gate arrival, wheels-off and wheels-on times, and aircraft tail number.

The annual data is available for download via the website: https://www.bts.gov/browse-statistical-products-and-data/bts-publications/airline-service-quality-performance-234-time. Some sample records from the 2019 ASQP are shown in Table 6.

Similar to the BTS's T-100 data, the ASQP also contains carrier activity (e.g., departures and arrivals). Though aircraft type information (i.e., fleet mix) is not directly available in the ASQP, it may be obtained in the FAA's registry data (introduced later on in this document) by using the reported tail number. Compared with the T-100 data, the disadvantage of using the ASQP to develop LTO and fleet mix data sets is that ASQP may have lower coverage of carriers and airports because of its reporting requirements.

[3] There are three flight-rule plans: (1) IFR Flight Plan. The flight plan is filed, and the flight is flown according to rules and regulations established by the FAA to govern flight under conditions in which flight by outside visual reference is not safe. IFR flight depends upon flying by reference to instruments in the flight deck, and navigation is accomplished by reference to electronic signals. (2) VFR Flight Plan. The flight plan is filed; however, the flight is flown solely by reference to outside visual cues (horizon, buildings, flora, etc.), which permit navigation, orientation, and separation from terrain and other traffic. (3) No-Flight-Plan. That is, no flight plan is filed, and the flight is flown under VFR.

However, ASQP contains the information required to estimate taxi-in and taxi-out times (i.e., gate arrival and departure times, and wheels-on and wheel-off times).

Table 6: Sample Records from ASQP in 2019

Carrier code	Dept airport	Arrival airport	Date of flight	Gate Departure Time (Actual) in Local Time	Gate Arrival Time (Actual) in Local Time	Wheels-Off Time	Wheels-On Time	Aircraft Tail Number
DL	CVG	ORD	20191201	1916	1935	1938	1928	N8896A
DL	CVG	ORD	20191202	1832	2009	2011	2001	N8896A
DL	JAX	RDU	20191201	622	743	637	738	N186PQ
DL	JAX	RDU	20191202	557	737	619	716	N316PQ
DL	LGA	PIT	20191201	1925	2056	1950	2050	N398CA
DL	LGA	PIT	20191202	0	0	0	0	N138EV
DL	PIT	LGA	20191201	2229	2357	2242	2350	N398CA
DL	PIT	LGA	20191202	0	0	0	0	N325PQ
DL	ATL	SGF	20191201	2037	2145	2111	2140	N925XJ
DL	ATL	SGF	20191202	2038	2128	2053	2124	N329PQ

Therefore, TTI may consider using the ASQP data to estimate the taxi-in and taxi-out times when applicable.

3.1.1.3 Airline Origin and Destination Survey (DB1B)

DB1B is a 10% sample of airline tickets sold by reporting carriers. This database is used to determine air traffic patterns, air carrier market shares, and passenger flows. Data includes the origin, destination, and other itinerary details of passengers transported.

The DB1B data is available for download for each quarter of a year via the website: https://www.transtats.bts.gov/DL_SelectFields.aspx?gnoyr_VQ=FLM&QO_fu146_anzr=b4vtv0%20n0q%20Qr56v0n6v10%20f748rB

Table 7 presents sample DB1B records with origin airports in Texas in the 1st quarter of 2019. The first record in the table suggests that American Airlines carried 71,139 passengers between the Dallas-Fort Worth International Airport (DFWIA) and Los Angeles International Airport (LAX) during this period.

Table 7: DB1B Sample Records

Passenger	Distance	Unique Carrier Name	Origin	Destination
71139	1235	American Airlines Inc.	DFWIA	LAX
56858	1121	American Airlines Inc.	DFWIA	MIA
52801	801	American Airlines Inc.	DFWIA	ORD
50899	868	American Airlines Inc.	DFWIA	PHX
50543	1379	United Air Lines Inc.	IAH	LAX
49320	862	United Air Lines Inc.	IAH	DEN
46834	239	Southwest Airlines Co.	HOU	DAL
45520	239	Southwest Airlines Co.	DAL	HOU
45443	1635	United Air Lines Inc.	IAH	SFO
44446	936	American Airlines Inc.	DFWIA	CLT
44285	1055	American Airlines Inc.	DFWIA	LAS
43898	190	American Airlines Inc.	DFWIA	AUS
43737	247	American Airlines Inc.	DFWIA	SAT

The advantage of DB1B for developing airport EIs is that it is quarterly data that can be used to capture the seasonality of air travel.

The disadvantages of the DB1B are:

1. The data is based on a sample of tickets sold and it only contains passenger information, which is difficult to translate into complete LTOs.
2. Since DB1B data is reported by carriers, it has issues like the T-100 segment data (i.e., limited coverage).

Based on its disadvantage, TTI does not recommend using DB1B as a primary data source to develop airport activity for airport EIs. However, TTI may consider using the data to develop or validate temporal patterns of airport activity.

3.1.2 Federal Aviation Administration

This section summarizes the FAA data sources assessed.

3.1.2.1 Airport Master Record

FAA's AMR consists of aeronautical data of both public and private use airports in the US. The data is collected on an as-needed basis, but the goal is to obtain an annual update for all the airports. The data is the FAA's source for the information used in aeronautical and flight information publications. For example, it is one of the data sources for the FAA's TAF. Specifically, the data includes information about available services (e.g., fuel), infrastructure (e.g., runway), aircraft operations, and based aircraft[4] by aircraft engine type at each airport.

The AMR is available for download via the website: https://adip.faa.gov/agis/public/#/airportSearch/advanced. Example records for airports in Harris County, Texas, are presented in Table 8.

The AMR plays an important role in developing aircraft activity for airport EIs in that it contains the aeronautical data of almost all the landing facilities in the US. Particularly, it contains the aircraft activity information for small GA airports in Texas, information which is of limited availability in other data sets. Though the aircraft activity data in the record is not given as LTOs by aircraft type, which is required by the AEDT, the data can be used as a basis for developing surrogate activity data or in QAQC procedures. Therefore, TTI may use the AMR to develop the aircraft activity for airport EIs.

3.1.2.2 Terminal Area Forecast

The FAA's TAF contains historical and forecast data for enplanements, airport operations, Terminal Radar Approach Control (TRACON) operations, and based aircraft. The data cover 264 FAA tower airports, 258 FAA contract tower airports, 153 TRACON facilities, and 2,770 non-FAA airports. Data in the TAF are presented on a US Government fiscal year basis (October through September). The TAF is prepared to assist the FAA in meeting its planning, budgeting, and staffing requirements. In addition, state aviation authorities and other aviation planners use the TAF as a basis for planning airport improvements.

TAF data is available for download at: https://www.faa.gov/data_research/aviation/taf/. Sample records for the Alice International Airport (ALI) are shown in Table 9.

TAF contains both historical and forecasts of aircraft operations and is based on aircraft data. The airport activity data consists of the following:

- Passenger enplanements served by air carriers, commuters, and air taxis.
- Itinerant operations for carriers, commuters, air taxis, GA, and military aircraft.
- Local operations for civil and military aircraft.
- TRACON operations for aircraft operations under radar control

[4] Based aircraft refers to aircraft that are operational & airworthy, which are typically based on the airport for a majority of the year.

Table 8: Sample Records from the AMR

Facility ID	55XA	XS38	67TS	83XS	12TA	HPY	T51	DWH
Facility Type	Heliport	Heliport	Heliport	Heliport	Heliport	Airport	Airport	Airport
Fuel Types			100			100LL A+	100LL	100LL A
Single Engine Aircraft	1					32	17	117
Multi-Engine Aircraft	1					12	1	14
Jet Engine Aircraft						2		5
Helicopters		1	1	1	1	3		0
Gliders Operational						0		0
Military Operational						0		0
Ultralights						0		0
Commercial Operations								5
Commuter Operations								
Air Taxi Operations								3279
GA Local Operations						10950	5400	42799
GA Itinerant Operations						10950	2400	51707
Military Operations								1683

Table 9: Sample Records for the Alice International Airport (ALI) from the TAF FY2021-2045 data.

ID	scenario[1]	Year	Itinerant Air Carrier	Itinerant Air Taxi	Itinerant General Aviation	Itinerant Military	Local General Aviation	Local Military	Total Flyover Operations	Single[2]	Jet[3]	Multi[4]	Helo[5]	Other[6]
ALI	0	2016	0	0	2200	20000	4400	0	0	11	0	3	4	0
ALI	0	2017	0	0	2200	20000	4400	0	0	9	0	3	4	0
ALI	0	2018	0	0	2200	20000	4400	0	0	9	0	3	4	0
ALI	0	2019	0	0	2200	20000	4400	0	0	5	0	0	3	0
ALI	1	2020	0	0	2200	20000	4400	0	0	4	0	0	2	0
ALI	1	2021	0	0	2200	20000	4400	0	0	4	0	0	2	0
ALI	1	2022	0	0	2200	20000	4400	0	0	4	0	0	2	0
ALI	1	2023	0	0	2200	20000	4400	0	0	4	0	0	2	0
ALI	1	2024	0	0	2200	20000	4400	0	0	4	0	0	2	0
ALI	1	2025	0	0	2200	20000	4400	0	0	4	0	0	2	0

[1]Scenario: historical – 0, forecast – 1.
[2]Single: total number of single-engine aircraft based at airport
[3]Jet: total number of jet-engine aircraft based at airport
[4]Multi: total number of multi-engine aircraft based at airport
[5]Helo: total number of helicopters based at airport
[6]Other: total number of other aircraft based at airport

The based aircraft is given by aircraft engine type, which is consistent with those in FAA's AMR.

In TAF, historical airport operations data for airports with FAA and FAA contract air traffic control services are reported by FAA air traffic and FAA contract tower staff. Operations at non-FAA airports are taken from FAA's AMR. The forecast of airport operations in TAF is a complex process. For example, to make a forecast of commercial operations at airports with more than 100,000 enplanements, TAF assumes a demand-driven forecast for aviation services based on local and national economic conditions as well as conditions within the aviation industry. In other words, an airport's forecast is developed independently of the ability of the airport and the air traffic control system to furnish the capacity required to meet demand. The forecast of commercial operations at airports with fewer than 100,000 enplanements is primarily based on an analysis of historical trends. The forecast of GA activity is made primarily based on time series analysis. The forecast for military activity and activity at non-FAA facilities are usually held constant unless otherwise specified by the FAA.

The major advantages of using TAF to develop activity for airport EIs are as follows:

1. It contains aircraft activity at airports (e.g., small GA airports) that other data sets (e.g., T-100 segment) do not cover. A comparison of the data from T-100 and TAF based on the information needed for airport EI activity development is given in Table 10. Since operations reported by FAA facilities include both commercial and GA operations, intuitively, the TAF should offer better activity coverage.
2. It also contains the historical and forecast based aircraft data which can be used to develop surrogate data.
3. Its forecasts of activity are used by state aviation authorities and other aviation planners as a basis for planning at airports.

Table 10: Comparison of the Activity Data between T-100 and TAF

Data Source	Data collecting method	Coverage	Resolution	Forecast
T-100 segment	Reported by carriers	Commercial operations	Monthly, aircraft type	No forecast
TAF	Reported by FAA facilities and AMR	Commercial, GA, and military operations	Annual (fiscal year), no aircraft type information	Forecast of activity

The disadvantages of using TAF are:

1. The forecast of commercial operations is "unconstrained", which means that the capacity constraints at airports may not be sufficiently reflected in the forecast. As a result, this forecast may overestimate future activity and therefore emissions.
2. As shown in Table 10, the activity in TAF is not given by aircraft type, physical, and user classes. In addition, the TAF does not cover all the landing facilities considered in the TTI airport EI. Other data sources or procedures are needed to estimate the activity at the landing facilities not included in the TAF. As a result, other data sources or procedures are needed to estimate the LTOs by aircraft type and user classes.
3. The operations are annual aggregations. As a result, the seasonality of the activity is not available.

The TTI study team suggests that the TAF be used to provide activity information (e.g., LTOs) directly and develop surrogate data for cases where activity information is unavailable.

3.1.2.3 Traffic Flow Management System Counts

Traffic Flow Management System Counts (TFMSC) are created from the information in the FAA's Traffic Flow Management System (TFMS). TFMSC data provides information on traffic counts by airport or by city pair for various data groupings such as aircraft type or by the hour of the day. It includes data for flights that fly under IFR and are captured by the FAA's en-route computers. Most Visual Flight Rules (VFR) and some non-en route IFR traffic are excluded (FAA 2022b).

The data is available for download from: https://aspm.faa.gov/tfms/sys/main.asp. Table 11 presents sample records at DFWIA from the TFMSC. The first record shows that A321 had about 3700 LTOs by carriers at DFWIA in Jan 2019.

Table 11: Sample Records from TFMSC at DFWIA Airport in Jan 2019

User	Physical	Flight	Aircraft	Departure	Arrival	Total
Air Carrier	Jet	Domestic	A321 - Airbus A321 All Series	3,682	3,688	7,370
Air Taxi	Jet	Domestic	CRJ9 - Bombardier CRJ-900	3,206	3,204	6,410
Air Carrier	Jet	Domestic	E170 - Embraer 170	1,896	1,894	3,790
Air Carrier	Jet	Domestic	E135 - Embraer ERJ 135/140/Legacy	1,824	1,814	3,638
Air Carrier	Jet	Domestic	MD83 - Boeing (Douglas) MD 83	1,472	1,475	2,947
Air Carrier	Jet	Domestic	CRJ7 - Bombardier CRJ-700	1,279	1,269	2,548
Air Carrier	Jet	Domestic	E145 - Embraer ERJ-145	501	499	1,000
Air Carrier	Jet	Domestic	E75L - Embraer 175	399	399	798
Air Carrier	Turbine	Domestic	C208 - Cessna 208 Caravan	308	311	619
Air Carrier	Jet	US to Foreign	B738 - Boeing 737-800	593	0	593

The main advantages of the TFMSC for developing activity for airport EIs are as follows:

1. It contains information that can be used to estimate fleet mix. Specifically, it has airport operations by aircraft type, physical, and user class. The aircraft types in the TFMFC can be mapped to the corresponding airframe and engine in the AEDT. The physical and user class information can be directly translated to the corresponding Source Classification Code (SCC).
2. The count is a daily count which can be used to capture the seasonality or weekly pattern of airport activity.

The main disadvantages of TFMSC are as follows:

1. It may not provide complete LTOs as most VFR and some non-en-route IFR operations are excluded. Further, for small airports with commercial services, the fleet mix information from the TFMSC may underestimate the percentage of operations by piston aircraft as they are more likely to fly under VFR or no-flight-plan rules.
2. Since most of the operations at small GA airports are under VFR or no-flight-plan rules, TFMSC may not offer good coverage for these airports.

FAA recently incorporated the Automatic Dependent Survelliance-Broadcast (ADS-B) data into its TFMSC. As a result, flight operations for aircraft equipped with ADS-B and flying under VFR or no-flight-plan rules could also be incorporated into the TFMS, which has the potential to improve the fleet mix representation and increase the coverage of the TFMSC.

TTI recommends that the TFMSC be used to develop activity data for airport EIs as it is one of the primary data sources that contain fleet mix information.

3.1.2.4 Operations Network

The Operations Network (OPSNET) is the official source of US air traffic operations and delay data. The data collected through OPSNET is used to analyze the performance of the FAA's air traffic control facilities. OPSNET records the activity at airports, control towers, TRACON, and air traffic control centers.

The OPSNET data is available for download via the website: https://aspm.faa.gov/opsnet/sys/main.asp

The records that can be used to develop activity for airport EIs are the airport operation count (arrivals and departures at an airport). The count is a measure of activity at FAA-funded airports, including Federal Contract Towers. This activity reports IFR itinerant and VFR itinerant operations (arrivals and departures), and local operations at the airport as reported by Air Traffic Control Towers (ATCT). It does not include overflights[5].

Table 12 shows some sample records for airports in TX. For the Abilene Regional Airport (ABI), there were 2,188 and 1,021 itinerant operations under IFR and VFR, respectively, and 1,542 local operations in September 2019.

Table 12: Sample Records from OPSNET for Some Airports in Texas in September 2019

	IFR Itinerant				VFR Itinerant				Local	
Facility	Air Carrier	Air Taxi	GA	Military	Air Carrier	Air Taxi	GA	Military	Civil	Military
ABI	20	664	658	846	0	30	782	209	592	950
ACT	12	340	1,354	1,082	2	57	1,616	56	1,846	82
ADS	1	515	3,334	10	0	76	7,073	24	317	0
AFW	598	294	1,121	1,095	1	14	3,427	145	5,380	490
AMA	685	500	595	798	0	34	316	81	657	541
AUS	11,828	1,341	2,508	213	1	19	1,373	203	48	28
BAZ	0	31	445	188	0	12	1,858	17	3,229	262
BPT	0	170	330	35	0	28	408	125	947	20

[5] Overflights: A terminal IFR flight that originates outside the ATCT's area and passes through the area without landing

The airport operation counts in OPSNET are similar to those in the TAF but with additional details on the counts under flight rules. Compared with TAF, the main disadvantages of the OPSNET are that it has a lower coverage of airports and does not offer forecasts of airport activity. The OPSNET only has historical airport operation counts at FAA-funded airports while TAF has the historical and forecast counts for both FAA-funded airports and non-FAA facilities.

As a result, TTI recommends using the OPSNETS data for validation and QAQC.

3.1.2.5Aviation System Performance Metrics

The Aviation System Performance Metrics (ASPM) contains information on 77 national commercial airports with significant activity. It provides efficiency and metrics data on flights to and from the 77 airports and flights by selected carriers. The ASPM database is created based on data in the TFMS, OOOI (Gate Out, Wheels Off, Wheels On, and Gate In) data, airline schedule data, BTS's ASQP data, and other carrier-reported data. Particularly, the ASPM provides the average taxi-in and taxi-out time at 77 ASPM airports, which are required activity inputs for AEDT.

The ASPM data is available for download via the website: https://aspm.faa.gov/apm/sys/TaxiTimes.asp. Table 13 presents sample records of taxi-in and taxi-out times from the ASPM.

Table 13: Sample Records from ASPM for January 2019

Facility	Scheduled Departures	Scheduled Arrivals	Average Taxi-Out Time (min)	Average Tax-In Time (min)
ABQ	2,184	2,186	14.54	5.2
ANC	3,539	3,640	14.38	5.73
ATL	34,622	34,547	17.29	8.47
AUS	5,155	5,160	13.56	5.92
BDL	2,570	2,567	13.52	5.42
BHM	1,661	1,661	15.17	3.54
BNA	6,635	6,639	14.54	6.16
BOS	14,955	14,955	20.13	8.25
BUF	2,229	2,228	20.01	5.16

The major advantage of using ASPM to develop activity for airport EIs is that it contains the average taxi-in and taxi-out times that are developed by using multiple data sources.

Some of the disadvantages of using ASPM are as follows:

1. It only has the taxi times for 77 ASPM airports, and only 6 airports are in Texas.
2. It contains only the average taxi-in/out times. In contrast, ASQP data could provide the taxi-in/out time of individual flights, which makes it possible to develop the temporal pattern of the taxi times.

TTI recommends using the average taxi times from the ASPM as inputs for AEDT. For the non-ASPM airports, the taxi times could be developed by using other data sources (e.g., ASQP and TFMS) or estimation methods such as those presented in (Lian et al. 2018; FAA 2022a).

3.1.2.6 Aircraft Registry

The FAA's Aircraft Registry (Registry) collects the information necessary to establish and maintain the record for all US civil aircraft.

The data is available for download on the website: https://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/releasable_aircraft_download/

Specifically, the registry data contains airframe and engine information of registered aircraft. Each aircraft in the registry has a unique ID (i.e., N-number or tail number), which could be used to link aircraft registry records to aircraft operations in other data sets to estimate fleet mix information. Figure 2 illustrates how to use N-number to determine the airframe and engine type of the flight records in BTS's ASQP data. The N-number of the aircraft in the first two records in Table 6 is "8896A". The airframe and engine type of the aircraft with this N-number in the registry data are Bombardier CL-600-2B19 and GE CF34 series.

The advantage of the registry data is that it contains the registry data of all US civil aircraft, which includes small GA aircraft whose activity are usually not very well collected. The registry data could be used to estimate the fleet mix of the LTOs if aircraft IDs are associated with the LTOs.

CODE	MFR	MODEL	TYPE	HORSEPOWER	THRUST
30015	GE	CF34 SERIES	5	0	9140

N-NUMBER	SERIAL NUMBE	MFR MDL CODE	ENG MFR MDL	YEAR MFR
8896A	7896	1390008	30015	2004

CODE	MFR	MODEL	TYPE-ACFT	TYPE-ENG	AC-CAT	BUILD-CERT-IND	NO-ENG	NO-SEATS	AC-WEIGHT	SPEED
1390008	BOMBARDIER INC	CL-600-2B19	5	5	1	0	2	55	CLASS 3	0

Figure 2: Sample records in 2019 FAA registration data

The disadvantages of the data are:

1. It does not have the registry data for military aircraft. Therefore, the fleet mix of military aircraft cannot be determined by using the registry data.
2. It does not contain information about the airports where registered aircraft are based. As a result, it cannot be used to directly determine the fleet mix of based aircraft at a landing facility.

TTI recommends that the FAA's registry data be used in the development of aircraft activity for airport EIs as it is the only comprehensive data set that can be used to determine or estimate the fleet mix of LTOs.

3.1.2.7 General Aviation and Part 135 Activity Survey

The GA Survey provides the FAA with information on GA and on-demand Part 135[6] aircraft activity. The survey enables the FAA to monitor the GA fleet so that it can anticipate and meet the demand for National Airspace System (NAS) facilities and services, assess the impact of regulatory changes on the fleet, and implement measures to assure the safe operation of all aircraft in the NAS. The survey population usually includes all civil aircraft registered with the FAA that are based in the US or its territories and that were in existence, potentially active in the survey year, and had a valid registration. The FAA's registry data provides the population from which a sample of civil aircraft is selected. In the sample design, aircraft are classified into aircraft types. The classification distinguishes between fixed-wing aircraft, rotorcraft, experimental aircraft, light-sport, and other aircraft. Within one major category, there are sub-categories based on type and engines.

The GA Survey summary data can be accessed on the website: https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/

The advantages of using the GA Survey to develop activity for airport EIs are as follows:

1. The survey has good coverage of the GA and part 135 population as it selects samples from all civil aircraft registered with the FAA that are based in the US or US territories.
2. The survey collects activity data such as hours flown and landings, which could be used to estimate GA and part 135 activity. It also collects information such as fuel

[6] A Part 135 operator provides commercial, non-scheduled aircraft operations, such as private air charter and air taxi flights.

consumption by region and aircraft type, which can be directly used to estimate emissions.

The main disadvantages of the GA Survey are as follows:

1. It does not cover the activity of the aircraft populations other than GA and part 135 (e.g., carriers and military).
2. The results that are available to the public are aggregated at the regional level while the AEDT requires inputs at the airport level. However, the regional level statistics could be used to develop airport-level surrogate data.

Given the fact that the survey has good coverage of the activity of GA and part 135 population, TTI recommends using the GA Survey data to estimate activity (e.g., surrogate activity data) at small GA landing facilities.

Table 14 summarizes the number of landings by region and aircraft type in the 2019 GA Survey. It can be observed that in the southwestern region, fixed-wing aircraft, single-engine piston, accounts for 60% of the total landings by fixed-wing aircraft. The activity of single-engine piston aircraft are usually not very well tracked in many of the data sets reviewed here as they usually fly under VFR or no-fly rules.

The main disadvantages of the GA Survey are as follows:

3. It does not cover the activity of the aircraft populations other than GA and part 135 (e.g., carriers and military).
4. The results that are available to the public are aggregated at the regional level while the AEDT requires inputs at the airport level. However, the regional level statistics could be used to develop airport-level surrogate data.

Given the fact that the survey has good coverage of the activity of GA and part 135 population, TTI recommends using the GA Survey data to estimate activity (e.g., surrogate activity data) at small GA landing facilities.

Table 14: Number of Landings by Region and Aircraft Type in the 2019 GA Survey

Aircraft Type	Region Aircraft Primarily Flown						
	Central	Eastern	Great Lakes	New England	Northwest Mountain	Southern	Southwestern
Fixed Wing - Piston							
1 Eng: 1-3 Seats	196,874	430,230	597,993	165,531	1,115,607	730,092	587,585
1 Eng: 4+ Seats	689,840	1,732,691	2,169,583	396,933	2,085,233	3,745,034	1,738,703
1 Engine: Total	886,714	2,162,922	2,767,576	562,464	3,200,840	4,475,126	2,326,288
2 Eng: 1-6 Seats	39,381	230,349	238,427	13,085	156,749	650,340	130,606
2 Eng: 7+ Seats	14,591	32,443	61,217	125,739	26,854	97,636	41,491
2 Engine: Total	53,972	262,792	299,644	138,824	183,603	747,976	172,097
Piston: Total	940,686	2,425,714	3,067,220	701,289	3,384,444	5,223,102	2,498,385
Fixed Wing - Turboprop							
1 Engine: Total	151,837	69,898	206,359	64,777	241,687	448,580	602,238
2 Eng: 1-12 Seats	38,501	42,291	68,744	6,177	90,186	96,112	103,720
2 Eng: 13+ Seats	14,261	27,413	43,888	23,540	177,140	137,682	47,566
2 Engine: Total	52,762	69,704	112,632	29,717	267,326	233,793	151,286
Turboprop: Total	204,599	139,602	318,991	94,494	509,013	682,374	753,524
Fixed Wing - Turbojet							
Turbojet: Total	134,985	337,024	411,185	65,442	288,097	534,219	596,207
Fixed Wing: Total	1,280,270	2,902,340	3,797,397	861,225	4,181,553	6,439,694	3,848,115
Rotorcraft							
Piston	*	136,507	142,415	38,687	291,836	367,262	185,492
1 Eng: Turbine	170,525	306,581	144,890	15,512	686,821	594,372	661,144
Multi-Eng: Turbine	*	227,629	95,726	33,235	256,072	132,296	261,196
Turbine: Total	*	534,209	240,617	48,747	942,893	726,668	922,341

3.1.2.8 National Plan of Integrated Airport Systems

The National Plan of Integrated Airport Systems (NPIAS) identifies nearly 3,310 existing and proposed airports that are included in the national airport system, the roles they currently serve, and the amounts and types of airport development eligible for federal funding under the Airport Improvement Program over the next 5 years.
The NPIAS contains all commercial service airports, all reliever airports, and selected public-owned GA airports.

The NPIAS data is available at: https://www.faa.gov/airports/planning_capacity/npias/. Some sample NPIAS records for airports in Texas are presented in Table 15. For activity data, NPIAS mainly contains information derived from based aircraft and passenger enplanements. That is, it does not provide aircraft activity data directly.

Table 15: Sample Texas Airport Records in NPIAS

Airport	Facility ID	Ownership	Hub	Role	Category		Current	
					Current	Year 5	Enplaned[2]	Based[3]
Abilene Regional	ABI	PU	N		P	P	77,229	105
Alice International	ALI	PU		Unclassified	GA	GA	0	6
Alpine-Casparis Municipal	E38	PU		Local	GA	GA	0	50
Rick Husband Amarillo International	AMA	PU	N		P	P	355,705	45
Chambers County	T00	PU		Basic	GA	GA	0	9
Andrews County	E11	PU		Local	GA	GA	0	25
Texas Gulf Coast Regional	LBX	PU		Local	R	R	15	23

[1]Acronyms: PU – Public Use, N – Non-hub, P – Commercial Service – Primary, GA – General Aviation Airport, R – Reliever Airport
[2]Enplaned - The number of revenue passengers that boarded aircraft at the airport during CY21(FY23).

[3]Based - This refers to the total count of aircraft registered and stored at the airport. This includes various types such as single engine, multiengine, jets, and helicopters. The count is based on the airport's records and has been verified through the N number registry. However, military aircraft, ultra-lights, gliders, and balloons are not included in this count.

As FAA has long recognized, the number of based aircraft is a valid indicator of an airport's activity levels (based on a strong correlation between based aircraft and operations). For airports requesting entry into the NPIAS, FAA requires validation-based aircraft counts. Therefore, the based aircraft counts in the NPIAS could be more accurate than those in other data sets (e.g., AMR). Therefore, TTI recommends that the based aircraft count data in NPIAS be used as a primary data source to develop activity data for airport EIs.

3.1.2.9 System-Wide Information Management Portal

In 2007, the FAA established the System Wide Information Management (SWIM) Program to implement a set of information technology principles and provide users with relevant and commonly understandable information. The SWIM Industry-FAA Team (SWIFT) is an FAA forum, open to the public, to provide a venue where participants can engage and learn about NAS data and information services along with other SWIM services to improve system integration, automation, system interoperability, and communication networks.

The SWIFT portal can be accessed on the website: https://portal.swim.faa.gov/. Access to the data in the portal requires logins and subscriptions. The registration and subscription process are described on the website: https://www.faa.gov/air_traffic/technology/swim/products/get_connected/

SWIFT bridges the gap between operations and technology, addressing questions and concerns raised regarding data sharing and information services.

- **Aeronautical** - Digital Notice to Air Missions, special activity airspace, and special user airspace notification and status. This data set might not be useful.
- **Weather** - Specialized weather products in the terminal area and runway visual range data. This data set may be used to provide meteorological conditions for the airport EI; however, the data covers a limited number of airports (about 70).
- **Surveillance** - Airport data such as surface movement events, tower departures, and airport configuration. This data set may be used to provide aircraft activity such as LTOs, and taxi-in and taxi-out times for the airport EI; however, the data covers a limited number of airports (about 100). The information on the LTOs and taxi times at these airports may also be covered by other data sets.

- **Flight/Flow** - Flight and flow information, metering status, flight plan, and track data. Particularly, the service contains the TFMS data. The TFMS data is the source for several other data sets reviewed in this document (e.g., ASPM and TFMSC). It includes the following data:
    - Terminal Flight data includes data exchanges involving surface movements and flow management. This data flow provides target times for movement area entry, off-block, and take-off and the projected wheels-up time. This data set may be useful to estimate taxi times, but it is currently only available for certain members.
    - Air Traffic Flow data consists of correlated aircraft flight data information received from various sources. Recently, several new features were added to this service. Specifically, more sophisticated tracking data, wider access to transponder codes, and access to ramp data are now available. Particularly, ADS-B data has been incorporated. ADS–B is an advanced surveillance technology that combines an aircraft’s positioning source, aircraft avionics, and ground infrastructure to create an accurate surveillance interface between aircraft and controllers. Aircraft must be equipped with ADS-B to fly in the most controlled airspace. Figure 3 presents a map of the ADS-B coverage over the airspace of Texas at and above 1,500 ft above the ground level. The figure shows that most of the airspace has ADS-B coverage. This suggests that ADS-B could track most of the aircraft activity including GA activity in Texas airspace.

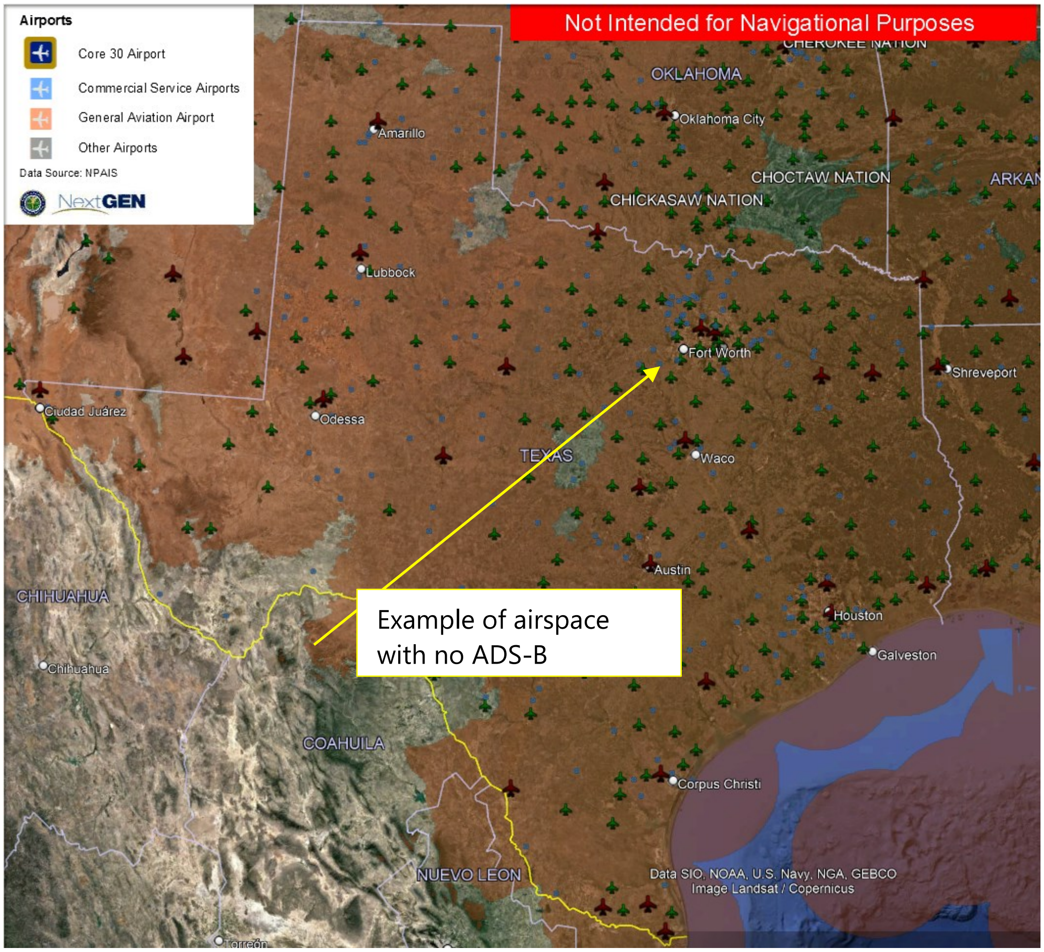

Figure 3: ADS-B coverage in the state of Texas at 1500' above ground level

A preliminary study of the ADS-B data done during this task concluded that both LTOs and fleet mix information can be obtained from the ADS-B data. Therefore, the TTI study team recommends that further exploration of the potential of using ADS-B data to develop activity for airport EIs be performed in the future.

3.1.2.10 Aerospace Forecast

The FAA Aerospace Forecast is developed to support the budget and planning needs of the FAA. The forecasts are developed using statistical models to explain and incorporate emerging trends in the different segments of the aviation industry. The forecasts cover US airline traffic and capacity, GA activity and pilots, as well as fleet information.

The forecasts can be accessed on this website: https://www.faa.gov/data_research/aviation/aerospace_forecasts/

Table 16 and Table 17 present the forecasts of growth rates for aircraft operations at towered airports and GA hours flown from 2021 to 2041, respectively. According to the forecasts, aircraft operations at towered airports are expected to grow while the activity of fixed-wing piston engine aircraft is expected to decline.

Table 16: Forecasts of Growth Rate for Aircraft Operations from 2021 to 2041

			General Avaiation			Military		
Fiscal Year	Air Carrier	Air Taxi/ Commuter	Itinerant	Local	Total	Itinerant	Local	Total
2010-20	-0.8%	-5.3%	-1.6%	0.5%	-0.6%	-0.9%	-2.4%	-1.6%
2020-21	-4.4%	-8.4%	4.7%	3.3%	4.0%	0.0%	0.0%	0.0%
2021-31	6.6%	1.2%	1.5%	0.9%	1.2%	0.0%	0.0%	0.0%
2021-41	4.2%	1.1%	0.9%	0.6%	0.8%	0.0%	0.0%	0.0%

Table 17: Forecasts of GA Hours Flown from 2021-2041

	Fixed-Wing - Piston			Fixed-Wing - Turbine		
As Of Dec. 31	Single Engine	Multi-Engine	Total	Turbo Prop	Turbo Jet	Total
2010-20	-0.3%	-0.6%	-0.4%	1.2%	-0.7%	0.1%
2020-21	0.3%	-1.1%	0.1%	2.9%	21.6%	13.1%
2021-31	-1.0%	-0.8%	-1.0%	1.0%	5.0%	3.5%
2021-41	-0.7%	-0.3%	-0.7%	1.0%	3.5%	2.6%

Compared with the forecasts in TAF, the Aerospace forecasts are at the national level. Therefore, the TTI study team does not recommend it be used as the primary data source for activity forecasts. Instead, the TTI study team suggests that it be used as a secondary data source to develop surrogate forecasts and validate results.

3.1.2.11 Voluntary Airport Low Emissions Program

FAA's Voluntary Airport Low Emissions (VALE) Program is designed to improve airport air quality and help airport sponsors meet their state-related air quality responsibilities. Through VALE, airport sponsors at commercial service airports located in areas that are in non-attainment or maintenance of National Ambient Air Quality Standards can use certain funds to finance low-emission vehicles, refueling and recharging stations, gate electrification, and other airport air quality improvements.

The VALE Grant Summary which summarizes the projects funded at airports can be accessed on this website: https://www.faa.gov/airports/environmental/vale/

Some records from the VALE grant summary are presented in Table 18. The project description in the summary details how the funding was spent (e.g., gate electrification) and airport sponsor contact information.

Table 18: Sample Records from VALE Program Summary FY 2015-2021

Airport Name	Airport Sponsor	ID	Hub	Project Description	Airport Sponsor Contact
Dallas-Fort Worth International	DFWIA Airport Board	DFW	L	Purchase and Installation of 10 dual-port chargers for 20 pieces of GSE	Sarah Ziomek (972) 973-5566 sziomek@dfwairport.com
San Antonio International Airport	City of San Antonio	SAT	M	Thirty-two (32) dual port eGSE charging stations	Steven Southers (210) 207-3559 Steven.Southers@sanantonio.gov
George Bush Intercontinental Houston	City of Houston	IAH	L	PCA for 5 gates and 68 charging ports	Carlos Ortiz (281) 233-1842 carlos.ortiz@houstontx.gov

The VALE grant summary could be used to obtain information about APU and GSE emission control measures. However, the summary may have limited coverage as many such emission control measures may not necessarily be funded through the VALE program.

3.1.3 Environment Protection Agency (EPA)

This section introduces the airport activity data prepared by the EPA which is provided to state, local, and tribal agencies to assist their submittal of aircraft-related activity data. EPA develops activity data (LTOs and fleet mix) from several FAA data sources including the following: T-100 dataset, TAF data, OPSNET data, and AMR data. The EPA's activity data is based on the T-100 data with the following hierarchy of additional data sources for adjustment of double counting:

1. OPSNET (adjust for double counting from T-100 if available)
2. TAF (adjust for double counting from T-100 if available)
3. AMR (adjust for double counting from T-100 if available)

As mentioned earlier in this document, T-100 data may not adequately capture GA activity. Though additional data sets that could capture GA activity are also used, they are mainly for the adjustment of double counting. Therefore, the TTI study team does not recommend the activity data from EPA be directly used. Instead, the TTI study team recommends the EPA's data be used as seed data to develop activity data or a secondary data set for validation and QAQC.

3.1.4 Energy Information Administration (EIA)

This section presents the EIA's projections for energy use by aviation activity.

3.1.4.1 Annual Energy Outlook

The Annual Energy Outlook (AEO) presents an assessment by the EIA of the outlook for energy markets through 2050. The AEO is developed using the National Energy Modeling System that captures interactions of economic changes and energy supply, demand, and prices. To account for uncertainties in the energy market, EIA develops different assumptions and methodologies to make multiple corresponding projections.

The data from EIA's AEO 2022 is available on this website: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=45-AEO2022&region=0-0&cases=ref2022&start=2020&end=2050&f=A&linechart=~~~~&map=&ctype=linechart&sourcekey=0

Particularly, the AEO makes projections of energy use for the transportation sector by mode and type. The AEO 2020 projections of the energy use for aviation activity under the reference case are shown in Figure 4.

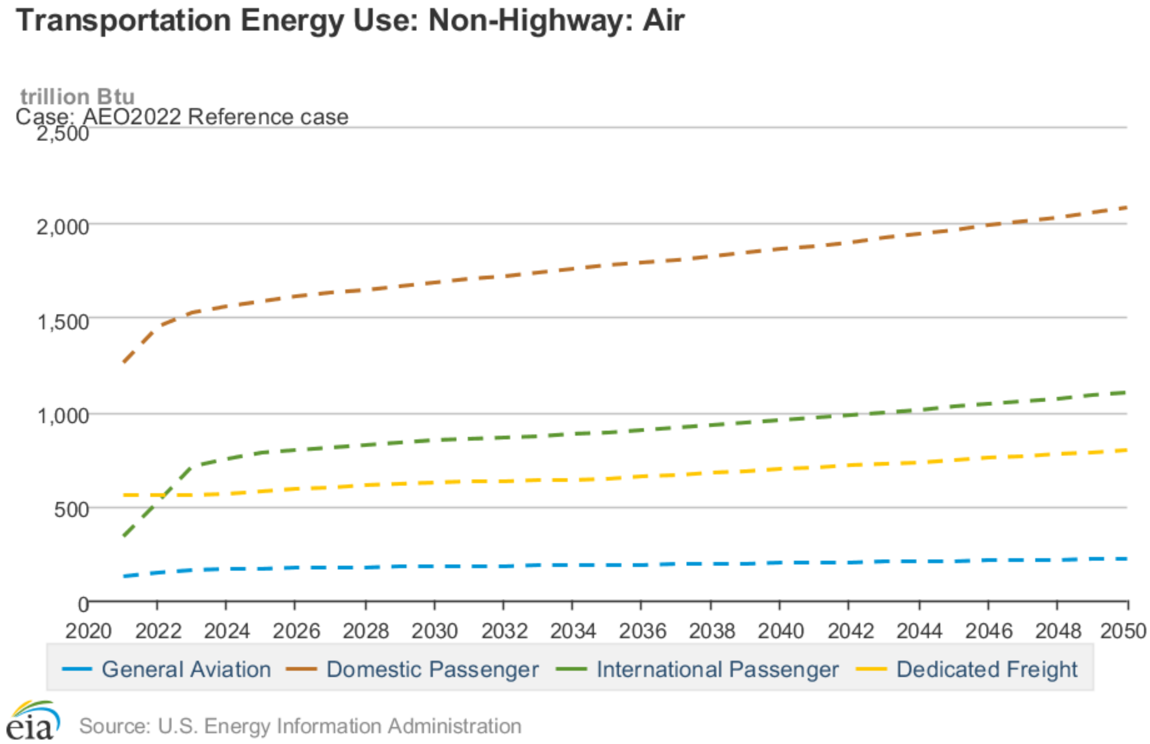

Figure 4: AEO 2022 projections of energy use by aviation activity under the reference case (EIA 2022)

3.1.5 Other Data Sources

This section summarizes other data sources TTI reviewed and assessed.

3.1.5.1 Official Airline Guide

OAG offers a historical commercial flight status database that includes millions of flights dating back to 2004. The database is developed based on data sources from airlines, airports, ADS-B data, and FAA data sets. Some of the information in the database may also be used by the FAA in the TFMS. However, access to OAG historical data services requires a paid subscription.

A review of the historical data service OAG offers can be found here: https://www.oag.com/historical-flight-data?hsLang=en-gb

Based on the review of the information provided on their website, the historical data contains information on LTOs, fleet mix, and taxi times; however, the data appears to be mainly for commercial flights. As mentioned earlier in this document, there are other free data sets (e.g., T-100) that may offer comparable statistics. Therefore, the TTI study team does not recommend that the historical data from OAG be used for aircraft activity development.

3.1.5.2 FlightAware

FlightAware is a digital aviation company that operates a flight tracking and data platform. Its main data sources include air navigation service providers, satellite service providers, ADS-B, and airlines. However, access to FlightAware historical data requires purchases.

A review of the custom report service is available here: https://flightaware.com/commercial/customreports/

Based on the review of the information provided on their website, FlightAware's historical flight tracking data may contain ground activity, taxi times, aircraft types, flight plans, and flight trajectories.

The advantage of the FlightAware historical data is that it is created by using multiple data sources (including ADS-B data). As a result, the data may have better coverage of GA activity. However, since the data requires purchase, the TTI study team recommends that the data from TFMS (which also includes information from ADS-B) be further explored to develop aircraft activity first. If the project budget permits, the FlightAware historical data can be purchased and used as a second data source to supplement the TFMS data.

3.1.5.3 AirNav.com

AirNav.com is a privately owned website for pilots and aviation enthusiasts. The site publishes aeronautical and landing facility information released by the FAA such as runway distances, airfield traffic patterns, airport operations, and based aircraft.

The information on the website is free but users can look up aircraft activity at only one land facility at a time. A preliminary comparison of the airport operations and based aircraft information from the website with those from the FAA’s AMR shows that the two sources are usually identical. Since the information on the website is mainly from FAA data, the TTI study team recommends using the corresponding FAA data whenever possible and using the data on this website as a secondary data source for validation and QAQC.

3.2 SUMMARY OF DATA SOURCES REVIEW

In summary, the TTI study team found that:

- Though there are free airport EI tools, AEDT is considered to be one of the most reliable and effective tools to develop airport EIs. Studies in the literature also suggest that collecting the necessary data for EIs can be a challenging task even for airport authorities. This may explain the low response rate of the survey approach that TCEQ used to collect data in past efforts. This also highlights the importance of using alternative data sources.
- Data availability for the flight activity of air carriers is relatively good in that multiple data sources can be used to develop carrier aircraft activity. Examples of such data sources are T-100, ASQP, DB1B, TAF, TFMS, SWIM-Portal, QAG, and FlightAware data.
- Data availability for flight activity under IRF other than carriers is also relatively good. Several data sources could provide information on such activity. Examples of such data sources are TAF, TFMS, SWIM-Portal, and FlightAware data.
- Since the rest of the aircraft activity are mostly under VFR or no-flight-plan rules at small GA airports, the availability of their activity data is limited. This is generally consistent with the findings in the literature (Muia 2007; 2000). Data sources that could be used for such activity include TAF, SWIM-Portal, and FlightAware data. As pointed out earlier in the document, ADS-B data may be a good data source for those flights. The study team will further explore ADS-B data in the subsequent task.
- The availability of data sources that contain forecasts of aircraft activity is also limited. Examples of such data sources include TAF, EIA-AEO, and Aerospace Forecasts. The forecasts in the latter two are given at the national level and therefore cannot be used directly. Procedures need to be developed based on their forecasts to generate forecasts of activity for AEDT.
- The study team found that publicly available data sources for APU and GSE emission control measures are limited. This may be due to the following:
    - the applications of alternatives to APU usage at gate areas at each airport can be different, which make it difficult to track the measures (Environmental Science Associates et al. 2012).
    - many airports do not track GSE information because some GSE is owned by airports and others by air carriers. Based on the literature

review so far, surveying airports or airlines may still be a good option to obtain the information.

- However, based on the airport GHG EI studies in the literature (e.g., the example in Figure 1), the aircraft LTOs produce the majority of GHG emissions while the GHG emissions by APU and GSE only account for a relatively small portion. From this point of view, APU and GSE emission control measures might have a limited impact on reducing total GHG emissions.

Table 19 presents a summary of how the data sources reviewed could be used to develop aircraft activity. In addition, how some of the data sources were used in TECQ's 2021 airport EI study are also presented in the table. Actual use of the data sources in the table is dealt with in the next section.

Table 19: Summary of Data Sources and Their Applications

Data sets	Cost	Frequency and time lag (approximate)	Data usage in (Madhusudhan et al. 2021)								Proposed data usage							
			LTOs			Fleet mix					LTOs			Fleet mix				
			Number	Temporal pattern	Forecast	Number	Temporal pattern	Forecast	Taxi times	APU&GSE	Number	Temporal pattern	Forecast	Number	Temporal pattern	Forecast	Taxi times	APU&GSE
T-100	Free open-source	monthly data, 6-month lag									Y	Y						
ASQP	Free open-source	monthly data, 3-month lag															Y	
DB1B	Free open-source	monthly data, 6-month lag										Y						
AMR	Free open-source	2-month update lag	1								Y			P				
TAF	Free open-source	published annually, 4-month lag to get the previous year's data	1		1			1			Y		Y	P		P		
TFMSC	Free open-source	daily data, 3-month lag		1		1	1				Y	Y		Y	Y		Y	
OPSNET	Free open-source	daily data, 3-month lag									Y			P				
ASPM	Free open-source	daily data, 4-month lag							1								Y	
Aircraft Registry	Free open-source	published annually, 4-month lag to get the previous year's data												Y				
GA Survey	Free open-source	published annually, 2-year lag to get the previous year's data									P			P				
NPIAS	Free open-source	published every 2 years																
SWIM-portal	Free open-source	near-real-time									Y	Y		Y	Y		Y	

Data sets	Cost	Frequency and time lag (approximate)	Data usage in (Madhusudhan et al. 2021)								Proposed data usage							
			LTOs			Fleet mix					LTOs			Fleet mix				
			Number	Temporal pattern	Forecast	Number	Temporal pattern	Forecast	Taxi times	APU&GSE	Number	Temporal pattern	Forecast	Number	Temporal pattern	Forecast	Taxi times	APU&GSE
Aerospace Forecast	Free open-source	published annually, 4-month lag to get the previous year's data									P			P				
VALE Grant Summary	Free open-source	unknown																Y
EIA - AEO	Free open-source	published annually			2						P			P				
EPA	Free open-source	provided annually									Y			Y				
OAG	Require purchase	unknown (airline schedules up to 6 months ahead)									Y	Y		Y	Y		Y	
FlightAware	Require purchase	unknown									Y	Y		Y	Y		Y	
AirNav.com	Free open-source	unknown	2								Y			P				
Databases in previous studies and surveys	Free		2				2			1								Y
AEDT Default									2	2								
Facility-provided data	Free	unknown	1			1			1	1								

1: primary data sets, used first

2: secondary data sets, used when no primary data is available

Y: data may be used directly or without significant processing efforts

P: data needs to be processed or procedures need to be developed to estimate the activity inputs needed

4 ACTIVITY DEVELOPMENT

This chapter covers the aircraft activity development that the TTI study team performed for this study under Task 4 - Data Processing, Analysis, and Development of Pre-processing Procedures. Major accomplishments under this task are listed below:

1. Developed procedures to estimate the LTOs at all landing facilities in Texas.
2. Developed procedures to estimate the fleet mix composition of the estimated LTOs.
3. Compared the estimated 2019 LTO data developed under this study with 2019 LTO data used in TTI's 2020 Airport AERR EI EI, which considers a similar set of landing facilities. In summary,
    - The total estimated LTOs in this study are about 10% higher than those used in the 2020 Airport AERR EI. The estimated LTOs for commercial airports are almost identical to those used in 2020 Airport AERR EI, and the estimated LTOs for reliever airports and other airports in the Texas Airport System Plan (TASP) is about 4-5% higher. The differences can be partially attributed to the current study completely utilizing the LTO data gathered from the FAA while in the previous TTI 2020 airport EI study, part of the LTO data were gathered from survey efforts.
    - Fundamental differences exist between the fleet mix developed in this study and those developed/used in the 2020 Airport AERR EI study. Notably, the total market share of aircraft with jet engines in this study is about 10% lower, and the total market share of aircraft with piston engines is about 10% higher. These differences are partly because this study develops fleet mix separately for itinerant LTOs and local LTOs. The latter are mainly performed by aircraft with piston engines.

Compared the fleet mix provided by the DFWIA with the one developed in this project. For aircraft with large share of LTOs, the fleet mix estimated in this project is close to those provided by DFWIA.

4. Investigated data sets that may provide additional information for estimating aircraft taxi times and usage of GSE and APU.

Both LTOs and associated fleet mix are developed mainly using regularly collected FAA data sets, which are free to the general public.

The TTI study team also investigated the possibility of using ADS-B data. However, it was decided not to use the data for the following reasons:

1. About 80% of the total LTOs required for developing EIs can be estimated using regularly collected FAA data sets.
2. Aircraft are required to be equipped with ADS-B to fly in most of the airspace in Texas. However, in discussions with a data vendor, the TTI study team learned that only a few data receivers are deployed to collect the data in many remote places in Texas. Therefore, data availability for small GA airports located in remote areas is not guaranteed.
3. The ADS-B data is not free, and it can cost up to 25 cents per flight record. It may not be financially practical to purchase the annual data for many airports.

However, if the receiver coverage improves in remote areas and the cost of the data decreases, then the TTI study team may reconsider the possibility of using ADS-B data to develop aircraft activity for future airport EI development.

Table 20 presents a summary of the data identified, how the data is used, and the associated processing efforts required. The TTI study team reviewed all the data sources and associated advantages and disadvantages in the previous chapter. For conciseness, the data used in this chapter will not be introduced again in this report.

The rest of this chapter is organized as follows. The first subchapter introduces the landing facilities considered in the study. The next subchapter describes the development of updated LTOs and fleet mix. Lastly, the report concludes with a subchapter with a summary of the developed LTOs and fleet mix.

Table 20. Summary of Data Used

Data sets	Cost	Frequency and time lag (approximate)	Data processing effort	Data usage							
				LTOs			Fleet mix			Taxi times	APU&GSE
				Number	Temporal pattern	Forecast	Number	Temporal pattern	Forecast		
ASQP	Free open source	monthly data, 3-month lag	Minimal		1		1	1	1	2	
AMR	Free open source	2-month update lag	Minimal, need to check format for consistency with previous versions	2			2		2		
TAF	Free open source	published annually, 4-month lag to get the previous year's data	Minimal	1		1	1		1		
TFMSC	Free open source	daily data, 3-month lag	A significant effort may be needed to update the mapping between aircraft types and AEDT equipment		1		1	1	1		
Aviation System Performance Metrics (ASPM)	Free open source	daily data, 4-month lag	Minimal							1	
Aircraft Registry	Free open source	published annually, 4-month lag to get the previous year's data	A significant effort may be needed to update the mapping between registered aircraft and AEDT equipment				1		1		
GA Survey	Free open source	published annually, 2-year lag to get the previous year's data	Minimal - Data formatting effort is needed	2			2		2		
Aerospace Forecast	Free open source	published annually, 4-month lag to get the previous year's data	Minimal			1	1				

Data sets	Cost	Frequency and time lag (approximate)	Data processing effort	Data usage							
				LTOs			Fleet mix			Taxi times	APU&GSE
				Number	Temporal pattern	Forecast	Number	Temporal pattern	Forecast		
Energy Information Administration (EIA) – Annual Energy Outlook (AEO)	Free open source	published annually	Minimal			2	2				
Databases in previous studies and surveys	Free		Minimal								1
AEDT Default	Free with software purchase		Minimal							2	2

1: primary data sets used first, **2:** secondary data sets used when no primary data is available

4.1 Landing Facilities

All the landing facilities within the state of Texas in the FAA's AMR (accessed in April 2022) are considered in this study. There are 2,080 landing facilities within Texas and FAA's AMR categorizes them into five groups based on their functionality and usage. Table 21 summarizes the distribution of these landing facilities among facility groups. Most of the facilities are airports and helicopter ports. Since gliders produce negligible emissions, glider ports are excluded from this study.

Table 21: Landing Facility Group Count

Facility Group	Facility Count
Airport	1,503
Gliderport	5
Heliport	561
Seaplane Base	3
Ultralight	8
Total	2,080

Table 22 presents the summary count of the landing facilities in each category. Figure 5 presents the locations of the landing facilities considered in this study. To maintain consistency, the TTI study team adopted the same facility categorization used in 2020 Airport AERR EI.

Table 22: Facility Count by Facility Category

Facility Category	Facility Count
Commercial	26
Farm/Ranch	464
Medical	186
Military	20
Other Private Airports	674
Other Private Heliports	349
Other Public Airports	97
Other Public Heliports	3
Reliever	25
TASP Airports	231
Total	2075

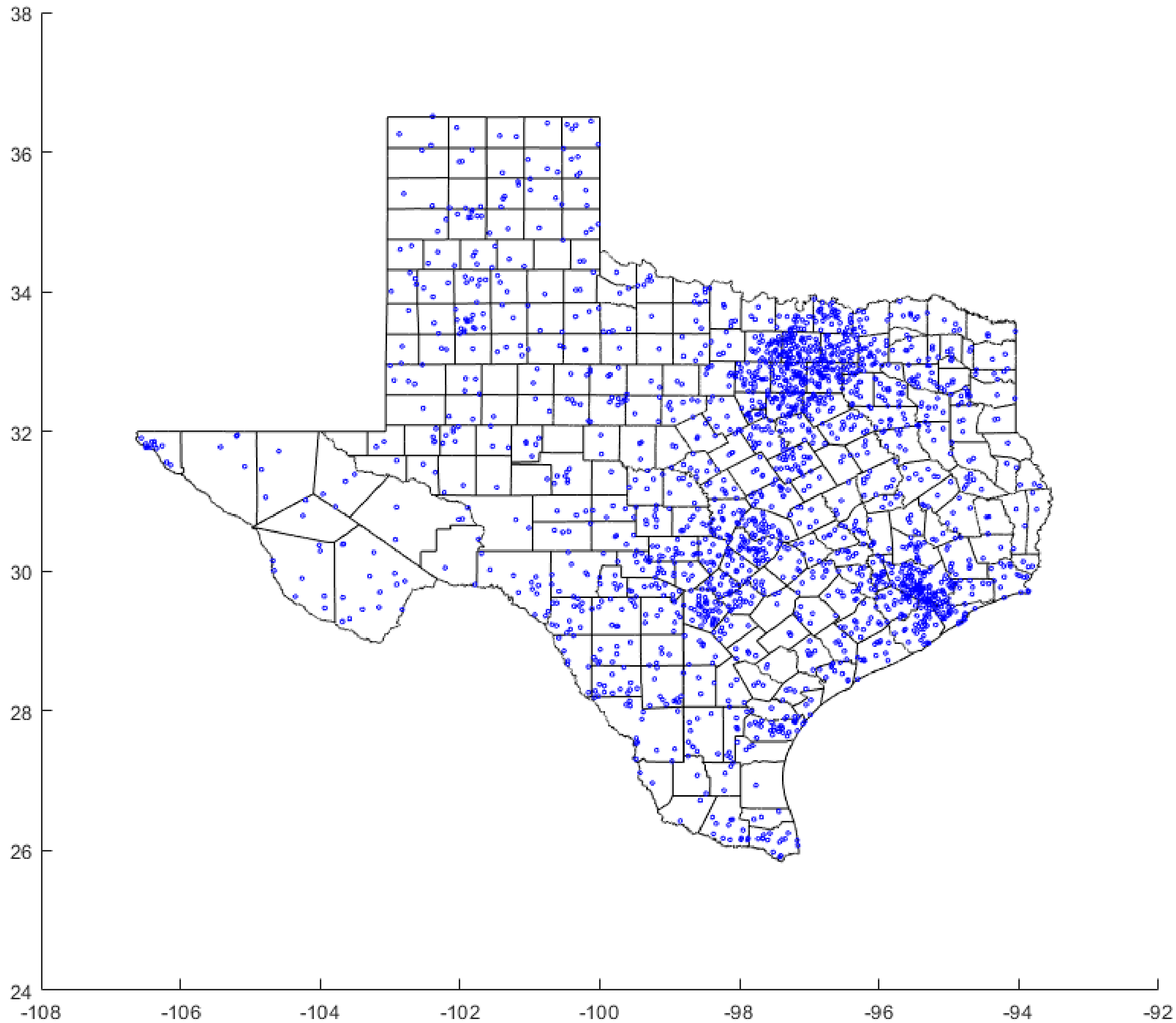

Figure 5: Locations of the landing facilities

The following subchapters present the development of LTOs and the corresponding fleet mix. Appendix A through D of this report provides a listing and characterization of the project Task 3 and Task 4 potential airport activity data sources analyzed and may be referred to for additional details on data sources and data sets mentioned or applied in the following subchapters.

4.2 Development of Landing and Take off Operations

This subchapter describes the development of LTOs and compares the newly estimated LTOs with those in TTI's latest airport EI, developed in 2021 for the TCEQ.

4.2.1 Methodology

This study applies a hierarchal approach to selecting the methods for developing airport LTOs. Figure 6 shows the four levels in the hierarchy, with level one data sources being the most preferred and level four being the least preferred choice for LTO data for a facility. In the first level, LTOs obtained from the TAF have precedence over other sources. In the second level, for airports where TAF data is not available, flight operation data from FAA's AMR is used to generate LTOs. In the third level, for landing facilities where neither TAF nor FAA's AMR provides LTOs, LTOs are estimated using base aircraft and the LTO rate (number of LTOs per aircraft). Base aircraft counts are from FAA's AMR and the LTO per aircraft is from FAA's GA survey data. In the fourth level, for landing facilities that are not captured in the above three sets of sources, LTOs are estimated as the average of the adjacent landing facilities (within a radius) of the same category.

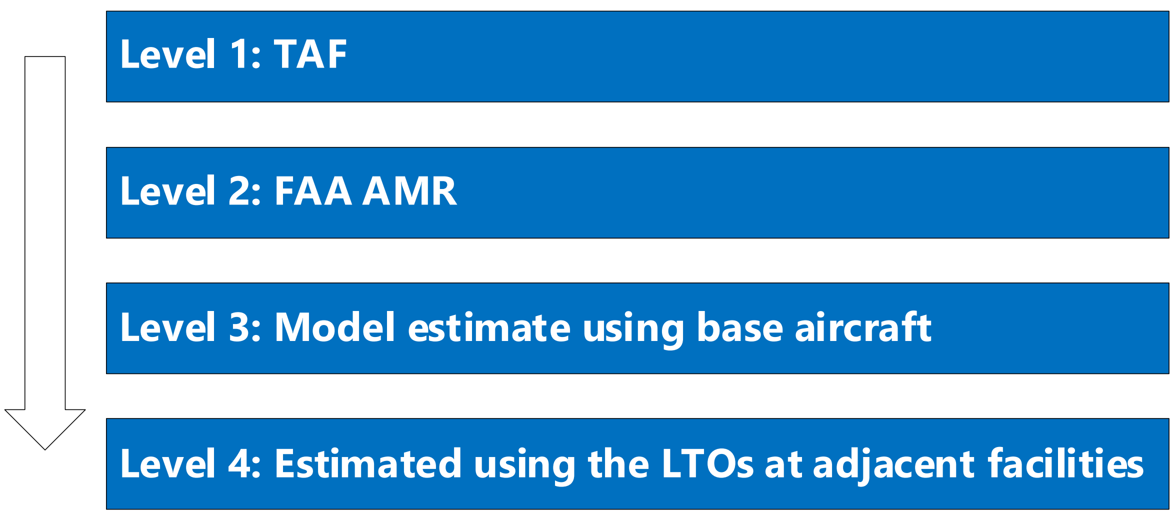

Figure 6: Methods hierarchy for developing LTOs

Table 23 summarizes the landing facilities count within each facility group, whose LTOs are available or can be estimated by each data source. Table 24 presents the corresponding number of LTOs estimated from each method or data source.

Table 23: Count of Landing Facilities Whose LTOs are Generated by Method or Data Source

Facility Category	Facility Count	L 1 (TAF)	L 2 (AMR)	L 3 (estimated using base aircraft)	L 4 (filled using adjacent facilities)	Not filled
Commercial	26	26	0	0	0	0
Farm/Ranch	464	0	39	226	199	0
Medical	186	0	4	30	152	0
Military	20	0	0	2	15	3
Other Private Airports	674	0	58	477	139	0
Other Private Heliports	349	0	4	134	211	0
Other Public Airports	97	0	83	10	4	0
Other Public Heliports	3	0	1	0	2	0
Reliever	25	25	0	0	0	0
TASP Airports	231	159	71	1	0	0
Total	2,075	210	260	880	722	3

Table 24: LTOs Generated by Data Source or Method

Facility category	LTOs by L 1 (TAF)	LTOs by L 2 (AMR)	LTOs by L 3 (Estimated using base aircraft)	LTOs by L 4 (filled using adjacent facilities)
Commercial	1,631,909	0	0	0
Farm/Ranch	0	29,096	18,355	18,916
Medical	0	1,721	3,618	21,809
Military	0	0	40,024	300,178
Other Private Airports	0	64,631	131,697	54,851
Other Private Heliports	0	2,053	12,860	27,488
Other Public Airports	0	298,472	6,968	13,735
Other Public Heliports	0	9	0	3,788
Reliever	1,081,653	0	0	0
TASP Airports	1,169,352	176,304	3,779	0
Total	3,882,913	572,285	217,301	440,765
Percent of Total	75.94%	11.19%	4.25%	8.62%

In the following sections, the methodology at each level is described.

4.2.2 LTOs Estimated from Terminal Area Forecast

TAF reports flight operations at a landing facility by seven categories: itinerant air carrier, itinerant GA, itinerant Air Taxi (AT), itinerant military, local GA, local AT, and local military. One flight operation refers to one take-off or landing. Therefore, the total LTOs at a landing facility is half of the total flight operations at the facility.

As shown in Table 23, the LTOs of 210 landing facilities are generated by using flight operation data from TAF. They account for about 10% of the total landing facilities considered. These 210 facilities include all commercial and reliever airports. As will be shown later on, the estimated LTOs at the commercial and reliever airports account for more than 50% of the total estimated LTOs at all landing facilities. The rest of the 210 facilities are TASP airports. The LTOs estimated using TAF account for about 75% of the total estimated LTOs for all landing facilities.

4.2.3 LTOs Estimated from the FAA Airport Master Record

FAA's AMR reports flight operations at a landing facility in 6 categories: commercial operations, commuter operations, AT operations, GA itinerant operations, GA local operations, and military operations. Similar to TAF, the total LTOs at an airport is half of the total flight operations at the facility.

As shown in Table 23, the LTOs of 260 landing facilities are generated by using flight operation data from AMR. They account for about 12% of the total landing facilities considered. These 260 facilities include 71 of the 231 TASP airports and the majority of other public airports. The LTOs estimated by using FAA's AMR account for about 11% of the total estimated LTOs of all landing facilities.

In levels 1 and 2 of the hierarchy method, TAF and FAA's AMR generate the LTOs for all commercial, relievers, and almost all TASP airports. These LTOs account for about 87% of the total estimated LTOs at all landing facilities. The rest of the landing facilities are generally small GA airports and their LTOs are estimated in level 3 by using the base aircraft or adjacent facilities of the same category.

4.2.4 LTOs Estimated by Using Base Aircraft

As mentioned earlier, most of the landing facilities whose LTOs cannot be generated by methods in the first two levels of the hierarchy are small GA airports. This study uses base aircraft at these airports to estimate their LTOs.

Base aircraft refers to aircraft that are operational and airworthy, and are typically based at the airport for the majority of the year. In the FAA's AMR, based aircraft are categorized into the following types:

- **Single Engine**: this category includes base aircraft with single-engine piston or turboprop engines.
- **Multiple-Engine**: this category includes base aircraft with multi-engine piston or turboprop engines.
- **Jet Engine**: this category includes base aircraft with jet or turbofan engines.
- **Helicopters**: this category includes base helicopters or rotorcraft.
- **Gliders:** this category includes base gliders.
- **Military:** this category includes military aircraft based at the airport.
- **Ultralights**: this category includes ultralight aircraft (e.g., balloons) based at the airport.

This study estimates the LTO rate (i.e., the number of LTOs per aircraft type) for each base aircraft category using the statistics from the FAA's GA survey. Specifically, the following two statistics are used:

- **Total landings by aircraft**: the data summarizes the total annual landings by aircraft during the survey year. The landings include landings made by both itinerant and local operations for all flight purposes. Since one landing is associated with one LTO and vice versa, the data offers an estimate of the total LTOs by aircraft.
- **Total active aircraft**: the data summarizes the total active aircraft during the survey year.

Table 25 provides the summary statistics for the total landings and active aircraft in the 2019 GA survey. Aircraft type outfitted with a single piston engine indicated the largest number of total active aircraft and account for the largest number of landings. Gliders and ultralights are excluded from the LTO estimation as they generated relatively little emissions compared with aircraft of other types. In addition, LTOs by air carriers are not estimated by this method as carriers' aircraft are usually not based at small GA airports and do not have a significant number of operations at these airports either.

Table 25: Total Landings and Active Aircraft in the 2019 GA Survey

Data	Piston 1 Eng	Piston 2 Eng	Turboprop 1 Eng	Turboprop 2 Eng	Turbojet	Rotorcraft
Total Landings	19,924,176	2,097,399	2,197,259	1,179,567	2,583,916	6,423,984
Estimated Number of Active Aircraft	128,926	12,470	5,111	5,131	14,888	10,199

Table 26 shows the LTO rate by base aircraft type. Helicopters have an LTO rate that is significantly higher than the other types. This suggests that helicopter ports and landing facilities with a large number of base helicopters tend to have higher LTOs.

Table 26: LTO Rate by Base Aircraft Type Based on 2019 GA Survey Data

Single Eng	Multi Eng	Jet Eng	Helicopter	Glider	Ultralight
165	186	174	630	51	80

Landing facilities may have restrictions on flight operations that can be performed. For example, landing facilities for private medical use may allow flight operations mainly for medical purposes only. Heliports will only allow flight operations by helicopters. At Farm/Ranch landing facilities, mainly local flights for agricultural applications are performed. Therefore, for landing facilities with possible restrictions on flight operations, discount factors need to be applied to the LTO rate to exclude the LTOs that are not permitted at the facilities.

This study uses the hours flown by flight use by aircraft type from the GA survey to approximate the discount factor. Table 27 presents the statistics from the 2019 GA survey. As shown in the table, there are 16 flight uses (ID from 1 to 16) ranging from personal or business use to medical or agricultural use. This study made the assumption that the average hours flown per LTO are similar among different flight uses. This assumption needs to be validated when necessary data is available.

Table 27: Total Hours Flown by Flight Use by Aircraft in the 2019 GA Survey

ID	Flight use	Operation type[1]	Piston 1 Eng	Piston 2 Eng	Turboprop 1 Eng	Turboprop 2 Eng	Turbojet	Rotorcraft
1	GA Use Total Active	N/A	12,700,321	1,731,098	1,440,662	1,178,429	3,926,485	2,996,531
2	GA Use Personal	Itinerant	5,422,045	418,914	112,319	114,937	393,385	102,073
3	GA Use Business w/o crew	Itinerant	860,921	213,718	111,859	80,713	234,543	34,813
4	GA Use Business w/crew	Itinerant	81,652	54,433	151,147	255,976	1,762,515	53,132
5	GA Use Instructional	Local	5,060,787	734,711	20,958	35,475	24,309	434,773
6	GA Use Aerial App Ag	Local	106,549	0	598,942	0	0	153,143
7	GA Use Aerial Obs	Local	330,816	49,091	14,709	18,851	0	515,112
8	GA Use Aerial App Other	Local	0	0	19,571	33,409	14,437	95,262
9	GA Use External Load	Itinerant	0	0	0	0	0	155,661
10	GA Use Other Work	Local	125,295	0	12,327	38,041	13,938	49,447
11	GA Use Sight See	Local	36,850	2,118	0	0	0	79,874
12	GA Use Air Med	Itinerant	31,180	2,674	0	5,460	3,381	19,686
13	GA Use Other	Local	380,145	55,412	73,934	65,545	170,635	136,987
14	On-Demand FAR Part 135 Use Air Taxi	Itinerant	201,118	188,248	248,945	467,961	1,216,872	439,368
15	On-Demand FAR Part 135 Use Air Tours	Local	52,367	0	11,133	1,968	0	240,644
16	On-Demand FAR Part 135 Use Air Med	Itinerant	0	0	60,794	46,258	88,494	486,558

[1] The operation type is assumed by this study.

The discount factor is calculated using the following formula:

$$discount_{at} = \frac{\sum_{id \in ID_p} hfu_{at,id}}{\sum_{id \in ID} hfu_{at,id}} = \frac{Total\ hour\ flown\ for\ all\ "permissible"\ flight\ uses}{Total\ hour\ flown\ for\ all\ flight\ uses}$$

Where

$discount_{at}$: the discount factor for aircraft type *at*.

$hfu_{at,id}$: the hours flew for flight use *id* (*id*s are specified in Table 27).

ID_p: the set of permissible flight uses.

ID: the set of all flight uses.

This study considered three sets of permissible flight uses for three facility categories:

- **Permissible set for private medical use airports**: at these airports, the flight uses for GA Use Air Med (ID 12) and On-Demand FAR Part 135 Use Air Med (ID 16) are allowed.
- **Permissible set for private farm/ranch airports**: at these airports, the flight uses for GA Use Aerial App Agriculture (ID 6), GA Use Aerial Obs (ID 7), and GA Use Aerial App Other (ID 8) are allowed.
- **Permissible set for other private airports**: at these airports, the flight uses for GA Use Personal (ID 2), GA Use Business w/o crew (ID 3), and GA Use Business w/crew (ID 4) are allowed.

The discount factors by aircraft type for the three permissible sets (given as a percentage) are summarized in Table 28. It can be observed that Helicopters are used more frequently at landing facilities for Medical and Farm/Ranch use than other aircraft types. At other private airports, fixed-wing aircraft are more frequently used.

Table 28: Discount Factors for LTO Rates at 3 Airport Categories by Aircraft Type

Aircraft Type	Medical	Farm/Ranch	Other private airports
Flight use (ID) permitted	12,16	6,7,8	2,3,4
Single Eng	0.65%	7.58%	47.71%
Multi Eng	1.89%	3.51%	39.48%
Jet Eng	2.34%	0.37%	60.94%
Helicopter	16.89%	25.48%	6.34%

For the other facility categories, no discount factors are developed (i.e., $discount_{at} = 1$).

The number of LTOs by each aircraft type is estimated as follows:

$$lto_{at} = discount_{at} \times ltorate_{at} \times bn_{at}$$

Where

at: is aircraft type.

$discount_{at}$: is the discount factor for aircraft type at.

lto_{at}: is the number of LTOs by aircraft type at.

bn_{at}: is the number of base aircraft for aircraft type at.

$ltorate_{at}$: is the LTO rate of aircraft type at.

The number of LTOs at an airport is the summation of the LTOs performed by all aircraft types.

As shown in Table 23, the LTOs of 880 landing facilities are estimated by using the base aircraft approach. Most of these airports are private-use airports. Based on Table 24, their estimated LTOs account for about 5% of the total estimated LTOs of all landing facilities.

For the landing facilities whose total LTOs are estimated in levels 1 and 2 of the hierarchy method, a breakdown of the total LTOs into itinerant and local LTOs is already available (they are reported in TAF and FAA's AMR). Itinerant and local LTOs are important in estimating the fleet mix of LTOs. However, this distinction is not available in LTOs estimated using the base aircraft approach. Therefore, the total LTOs estimated in this hierarchy are further disaggregated into itinerant and local LTOs. To do so, the shares of itinerant and local LTOs by aircraft type and user class are estimated using the statistics in Table 27. The share estimates are summarized in Table 29. For landing facilities where all flight uses are permissible, the general shares will apply. For the landing facilities in the three facility categories that have permissible flight uses, the share estimates in the corresponding facility category will apply.

Table 29: Share of Itinerant and Local LTOs by Aircraft Type

User class	Single Eng	Multi Eng	Jet Eng	Helicopter
General				
Itinerant GA	47.90%	39.80%	61.00%	12.20%
Local GA	48.00%	35.80%	5.70%	48.90%
Itinerant AT	3.60%	24.40%	33.30%	30.90%
Local AT	0.40%	0.10%	0.00%	8.00%
Private Medical use				
Itinerant GA	33.90%	15.00%	3.70%	3.90%
Local GA	0.00%	0.00%	0.00%	0.00%
Itinerant AT	66.10%	85.00%	96.30%	96.10%
Local AT	0.00%	0.00%	0.00%	0.00%
Private Farm/Ranch use				
Itinerant GA	0	0	0	0
Local GA	100%	100%	100%	100%
Itinerant AT	0	0	0	0
Local AT	0	0	0	0
Other Private Use				
Itinerant GA	100%	100%	100%	100%
Local GA	0	0	0	0
Itinerant AT	0	0	0	0
Local AT	0	0	0	0

The itinerant and local LTOs by aircraft type and user class are calculated using the following equations:

$$Itnlto_{u,at} = Itnshare_{u,at} * lto_{at}$$

$$Loclto_{u,at} = Locshare_{u,at} * lto_{at}$$

Where

$Itnlto_{u,at}$: is the itinerant LTOs for user class u by aircraft type at

$Loclto_{u,at}$: is the local LTOs for user class u by aircraft type at

$Itnshare_{u,at}$: is the share of itinerant LTOs for user class u by aircraft type at. The share is given in Table 29.

$Locshare_{u,at}$: is the share of local LTOs for user class u by aircraft type at. The share is given in Table 29.

The itinerant and local LTOs are estimated as follows:

$$Itnlto = \sum_{u,at} Itnlto_{u,at}$$

$$Loclto = \sum_{u,at} Loclto_{u,at}$$

Where

$Itnlto$: is the itinerant LTOs

$Loclto$: is the local LTOs.

4.2.5 LTOs Estimated by Using Adjacent Landing Facilities

In the FAA's AMR, there are about 720 landing facilities that have no reported base aircraft and flight operations in TAF or FAA's AMR. The base aircraft approach in level 3 of the hierarchy method does not work for these airports. The majority of them are small private GA landing facilities and their LTOs are expected to account for a small portion of the total LTOs.

This study uses the mean LTOs (including the itinerant and local LTOs) of its adjacent landing facilities which are in the same facility category and have estimated LTOs. The assumption behind this approach is that adjacent facilities of the same category tend to have similar flight operations.

This study uses a radius to identify the adjacent facilities of a facility (center facility). The adjacent facilities of the center facility are those within its radius. This study uses 20 miles as the initial radius. If no adjacent facilities exist within the radius used, the radius is increased by 100 miles and the adjacent facilities within the new radius are determined and used. The process is repeated until adjacent facilities are found or the radius exceeds 1,000 miles (in this case this study assumes that no such adjacent facility exists within Texas).

As shown in Table 23, the LTOs of 722 landing facilities are estimated by the mean LTOs of adjacent facilities. Most of the 722 landing facilities are private-use airports. Based on Table 24, their estimated LTOs account for about 9% of the total estimated LTOs of all landing facilities.

4.2.6 Summary Statistics

This subchapter compares the LTOs estimated by this study (current LTOs) with those used to devlop TCEQ's 2020 Airport AERR EI (2020 Airport AERR EI LTOs). The estimates of current LTOs for Texas landing facilities produced for this study are provided in Appendix A.

Table 30 presents the current LTOs and the 2020 Airport AERR EI LTOs by facility category and their corresponding percentages in the total LTOs. The total number of current LTOs is about 10% higher than that of the 2020 Airport AERR EI LTOs. The largest difference occurs in the Other Public Heliports facilities category. The current LTOs for this category is about 30 times higher than those in the 2020 Airport AERR EI LTOs. This could be partially due to the high LTO rate identified for helicopters and all flight uses are permissible at public landing facilities. In reality some flight uses may not be allowed at some public heliport facilities, which could reduce helicopter's LTO rate and hence LTOs at the public heliport facilities. Note that the LTOs for this category only account for less than 0.1% of the total LTOs. Therefore, it is reasonable to expect the overestimates of this facility category may not significantly impact the EI.

Table 30: LTOs Comparison by Facility Category

Facility Category	LTOs (Current Study)	Percent (Current Study)	LTO (2020 Airport AERR EI)	Percent (2020 Airport AERR EI)	Percent Difference
Commercial	1,631,909	31.9%	1,636,508	35.4%	-0.3%
Farm/Ranch	66,367	1.3%	61,128	1.3%	8.6%
Medical	27,148	0.5%	16,163	0.3%	68.0%
Military	340,202	6.7%	153,408	3.3%	121.8%
Other Private Airports	251,179	4.9%	109,577	2.4%	129.2%
Other Private Heliports	42,400	0.8%	21,030	0.5%	101.6%
Other Public Airports	319,174	6.2%	300,045	6.5%	6.4%
Other Public Heliports	3,797	0.1%	119	0.0%	3090.9%
Reliever	1,081,653	21.2%	1,042,653	22.5%	3.7%
TASP Airports	1,349,435	26.4%	1,287,441	27.8%	4.8%
Total	5,113,263	100.0%	4,628,070	100.0%	10.5%

The current LTOs for commercial airports are 0.3% lower than the previous ones. Table 31 presents the comparison of LTOs at each of the 26 commercial airports. The LTOs at Dallas Love Field Airport (DAL) account for about 7% of the total LTOs at commercial airports statewide. DAL indicates the largest difference. The current LTOs for DAL is about 8% higher than the 2020 Airport AERR EI LTOs. The LTOs for Abilene Regional Airport (ABI) and Del Rio International Airport (DRT) are about 5% lower and 4% higher than the 2020 Airport AERR EI LTOs, respectively. The combined LTOs at the two airports account for about 2% of the total LTOs at commercial airports statewide. The LTOs at Dallas/Fort Worth International Airport (DFW) account for about 22% of the total LTOs at commercial airports statewide, which is the highest. The current LTOs are about 2.5% lower than those used in the previous study.

Table 31: Comparison of LTOs at Commercial Airports

Location Id	County	LTOs (Current Study)	LTO (2020 Airport AERR EI)	Difference
ABI	TAYLOR	24,969	26,212	-4.74%
AUS	TRAVIS	104,142	103,603	0.52%
BRO	CAMERON	14,188	14,189	-0.01%
CRP	NUECES	50,709	50,709	0.00%
DFW	TARRANT	351,579	360,004	-2.34%
DAL	DALLAS	114,797	106,018	8.28%
DRT	VAL VERDE	10,730	10,315	4.02%
CLL	BRAZOS	28,793	28,791	0.00%
GGG	GREGG	27,835	27,834	0.00%
ELP	EL PASO	43,340	43,340	0.00%
IAH	HARRIS	237,078	239,035	-0.82%
BPT	JEFFERSON	9,180	9,180	0.00%
LRD	WEBB	36,787	36,786	0.00%
LBB	LUBBOCK	45,929	45,928	0.00%
MFE	HIDALGO	31,739	31,739	0.00%
MAF	MIDLAND	32,253	32,253	0.00%
AMA	POTTER	28,805	28,805	0.00%
SJT	TOM GREEN	38,829	38,828	0.00%
SAT	BEXAR	82,774	82,773	0.00%
SPS	WICHITA	112,762	114,336	-1.38%
ILE	BELL	14,183	14,180	0.01%
TYR	SMITH	17,292	17,292	0.00%
HRL	CAMERON	20,344	20,343	0.00%
VCT	VICTORIA	28,007	28,006	0.00%
ACT	MC LENNAN	23,657	23,657	0.00%
HOU	HARRIS	101,216	102,352	-1.11%

The current LTOs for relievers is about 4% higher than those in the 2020 Airport AERR EI LTOs. Table 32 presents the comparison for each reliever airport. Ellington Airport (EFD) accounts for about 5% of the total LTOs at reliever airports statewide. The current LTOs for EFD are about 48% higher than those used in the previous study. The difference is the largest among all reliever airports. Dallas Executive Airport (RBD) and Stinson Municipal Airport (SSF) account for 6% of the total LTOs at reliever airports statewide, respectively. The current LTOs at these two airports are about 25% and 27% higher than those used in the previous study, respectively.

Table 32: Comparison of LTOs at Reliever Airports

LocId	County	LTOs (Current Study)	LTO (2020 Airport AERR EI)	Difference
ADS	DALLAS	57,874	57,873	0.00%
GKY	TARRANT	39,383	39,876	-1.24%
CXO	MONTGOMERY	46,421	46,420	0.00%
RBD	DALLAS	22,724	22,723	0.00%
DWH	HARRIS	62,366	49,736	25.39%
DTO	DENTON	69,982	69,981	0.00%
EFD	HARRIS	55,925	37,699	48.35%
AFW	TARRANT	63,786	63,785	0.00%
FTW	TARRANT	81,954	81,954	0.00%
FWS	TARRANT	33,597	33,596	0.00%
GTU	WILLIAMSON	54,391	54,390	0.00%
GPM	TARRANT	47,158	47,158	0.00%
AXH	FORT BEND	21,312	21,749	-2.01%
SKF	BEXAR	428	427	0.19%
LNC	DALLAS	33,550	34,039	-1.44%
T41	HARRIS	14,525	14,864	-2.28%
TKI	COLLIN	78,761	78,760	0.00%
HQZ	DALLAS	26,815	26,815	0.00%
LVJ	BRAZORIA	30,000	30,569	-1.86%
HYI	CALDWELL	29,993	31,977	-6.20%
GLS	GALVESTON	14,610	15,027	-2.77%
SSF	BEXAR	67,114	52,656	27.46%
SGR	FORT BEND	38,497	38,497	0.00%
LBX	BRAZORIA	38,991	39,848	-2.15%
IWS	HARRIS	51,500	52,235	-1.41%

An important factor that could be contributing to the differences in the LTO estimates between the current study and those used in the previous study is that discrepancies may exist in the data sources used. Data obtained from directly surveying airport staff is one of the data sources used to develop the 2020 Airport AERR EI LTOs at commercial and reliever airports. In contrast, the LTOs devloped as part of the current study for these airport categories are estimated entirely from TAF. Since these airports are all towered airports, their flight operation data is usually collected by air traffic control staff. While it is understandable that discrepancies may exist between the two data sets as they may be collected and processed by different staff or using different methods, the discrepancy highlights the necessity of data syncretization.

The current study LTOs for the TASP airports are about 5% higher than those devloped in the 2020 Airport AERR EI study. A plot of airport-level comparison is shown in Figure 7. For the majority of the TASP airports, their current LTOs are close to those used in the previous study. Desoto Heliport (73T) has the largest difference, with a total of3 LTOs identified in in the previous study 2020 Airport AERR EIwhile its current LTOs are about 3,780. It is the only TASP airport whose current LTOs are estimated by using the base aircraft method in level 3. According to the latest information on AirNAV.com, there are 6 base helicopters at the airport. Based on the LTO rate in Table 26, its current LTOs could be a more reasonable estimate. Since the LTOs for the rest of the TASP are either from TAF or FAA's AMR, the difference in the LTOs could be partly because of the discrepancy between the data from the survey and the data reported to the FAA.

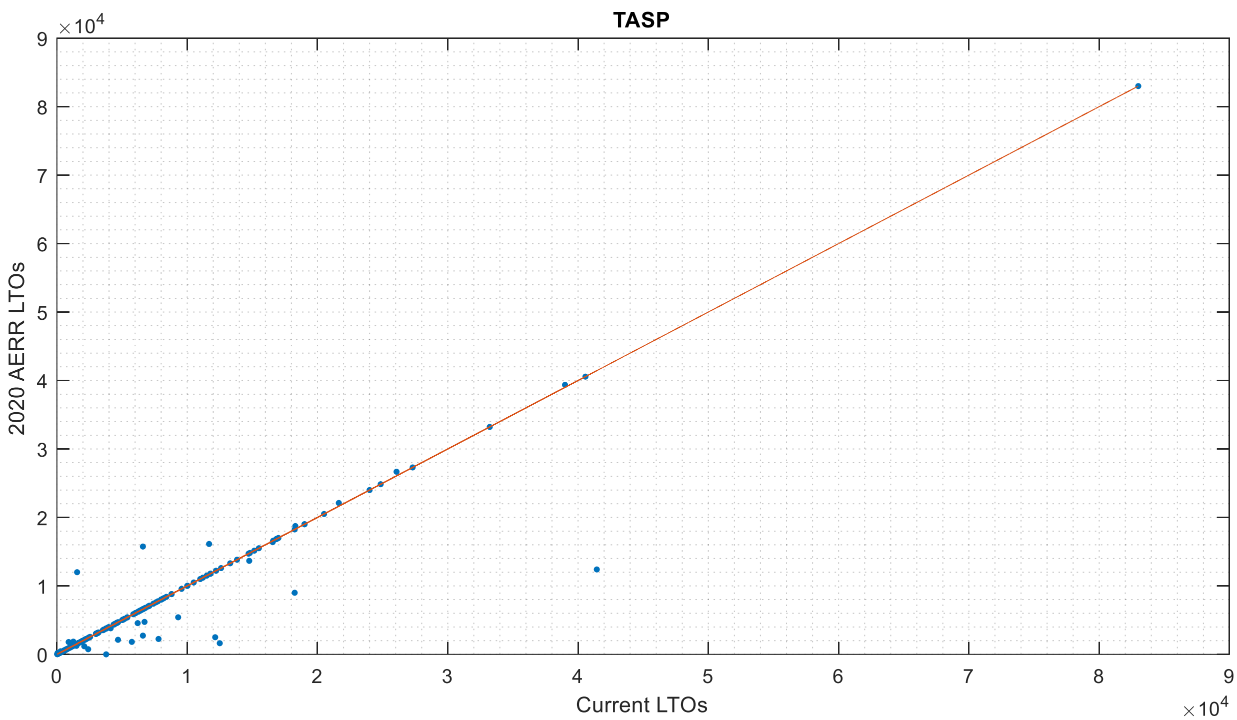

Figure 7: Comparison of the LTOs at the TASP airports

4.3 Development of Fleet Mix

In AEDT, an aircraft is defined by an AEDT aircraft equipment combination (for brevity, "equipment"), which consists of an airframe and an engine. Figure 8 presents two examples of AEDT equipment with their associated airframes and engines. The latest version of AEDT contains 3,579 pieces of equipment, which are created using combinations of 1,158 individual airframes and 1,050 individual engines. An AEDT equipment is not an arbitrary combination of airframe and engine. Instead, they are created based on factors such as the availability of aircraft performance and emissions data.

AEDT airframe

AIRFRAME_ID	MODEL	ENGINE_COUNT	USAGE_CODE	SIZE_CODE	ENGINE_TYPE
4581	Boeing 707-100 Series	4	P	H	J
4964	Robinson R22	1	H	S	P

AEDT equipment

EQUIP_ID	AIRFRAME_ID	ENGINE_ID	ANP_AIRPLANE_ID	ANP_HELICOPTER_ID	BADA_ID
1	4964	1594	NULL	H500D	P28A
55	4581	1258	707120	NULL	B703

ENGINE_ID	ENGINE_CODE	MANUFACTURER	MODEL	ENGINE_TYPE
1258	1PW001	Pratt & Whitney	JT3D-3B	J
1594	O320	NULL	O-320	P

AEDT engine

Figure 8: Examples of AEDT airframe, engine, and equipment

AEDT evaluates the emissions of the AEDT equipment. To develop an airport EI, the estimates of aircraft LTOs need to be assigned to AEDT equipment. The fleet mix of LTOs refers to the distribution of LTOs among the AEDT equipment.

2020 airport AEERR EI, the fleet mix was developed using the TFMSC data. TFMSC data contains the flight operation data by aircraft type and user class (e.g., commercial and GA). The shares of aircraft types can be calculated directly from the data. However, aircraft types in the TFMSC data are not the same as the AEDT equipment. Therefore, a mapping between the TFMSC aircraft types and AEDT equipment was created. Using this mapping, the shares of aircraft types were converted to the shares of AEDT equipment. The fleet mix is calculated by multiplying the total LTOs by the shares of AEDT equipment. For landing facilities that have no TFMSC data, a substitute fleet mix is developed based on simple assumptions about the aircraft and their market shares.

This study improves the development of fleet mix in the following ways:

1. Used FAA's ASQP data and aircraft registration data to estimate the fleet mix of commercial flight operations at major commercial airports. The two data sets provide more detailed aircraft information than the TFMSC data does, possibly improving the emissions estimates for commercial flight operations.
2. Improved the method for developing a substitute fleet mix for landing facilities that do not have ASQP and TFMSC data. Note that the majority of landing facilities in Texas are not covered by the two data sets.
3. Improved the mapping between the aircraft types in TFMSC data and AEDT equipment. Examples of improvement include the addition of mappings for aircraft types that were not mapped to AEDT equipment previously and revisions to AEDT engines for some existing mappings to improve accuracy.

4.3.1 Mapping Between Aircraft Registration Records and AEDT Equipment

FAA's registration data contains about 290,000 unique aircraft records. Each registered aircraft is assigned a unique ID called N-number. Each registration record contains the aircraft model and engine model information of the registered aircraft. FAA's registration data serves two key roles in the fleet mix development

1. Detailed aircraft information for the aircraft in ASQP data can be obtained from the registration data. The ASQP data contains the N-number of the aircraft, which can be used to retrieve its aircraft model and engine model from the registration data.
2. The market share of AEDT equipment is estimated using the registration data. The market share estimates are used to develop, for example, the substitute fleet mix.

2020 Airport AERR EIAn important step in developing fleet mix using the registration data is to establish a mapping between the aircraft record in the registration data and

AEDT equipment. This study only considers fixed-wing aircraft and rotorcraft when creating the mapping as the other aircraft types (e.g., gliders and balloons) generate negligible emissions. As shown in Table 33, the two aircraft types account for about 95% of the total registered aircraft. However, due to issues such as inconsistencies in the airframe and engine specifications between AEDT and registration data, it is challenging to assign each record to an AEDT equipment manually. Therefore, the TTI study team developed a two-step method to create the mapping. The assignment statistics in each step are summarized in Table 33.

Table 33: Percentage of Assignments for Airframe, Engine, and Equipment

Total records	Total records considered	Airframe mapping (step 1)	Engine mapping (step 1)	Equipment mapping (step 1)	Equipment mapping (step 2)
290,100	276,844	185,207	187,792	93,460	261,192
Percentage of assigned	95.43%	66.90%	67.83%	33.76%	94.35%

Step 1: Create an airframe mapping and an engine mapping between the registration data and AEDT separately.

Airframe mapping - The development of airframe mapping is largely a manual process. For each AEDT airframe, the study team members determine its corresponding aircraft model from within the registration data by finding the airframe model with the model name matching the AEDT airframe name as close as possible (as visualized in Figure 9). As shown in Table 33, about 67% of the registration records are assigned an AEDT airframe using airframe mapping.

Engine mapping - A similar approach is used to create the engine mapping (as visualized in Figure 9). Since the engine naming and specifications in the two data sets are relatively consistent, an excel script is developed to find the engine name match between the two data sets automatically first. Then a manual process is used to create more matches based on factors such as whether two engines are similar variants of the same engine or have similar performance in terms of horsepower and the number of cylinders. About 68% of registration records are assigned an AEDT engine with engine mapping.

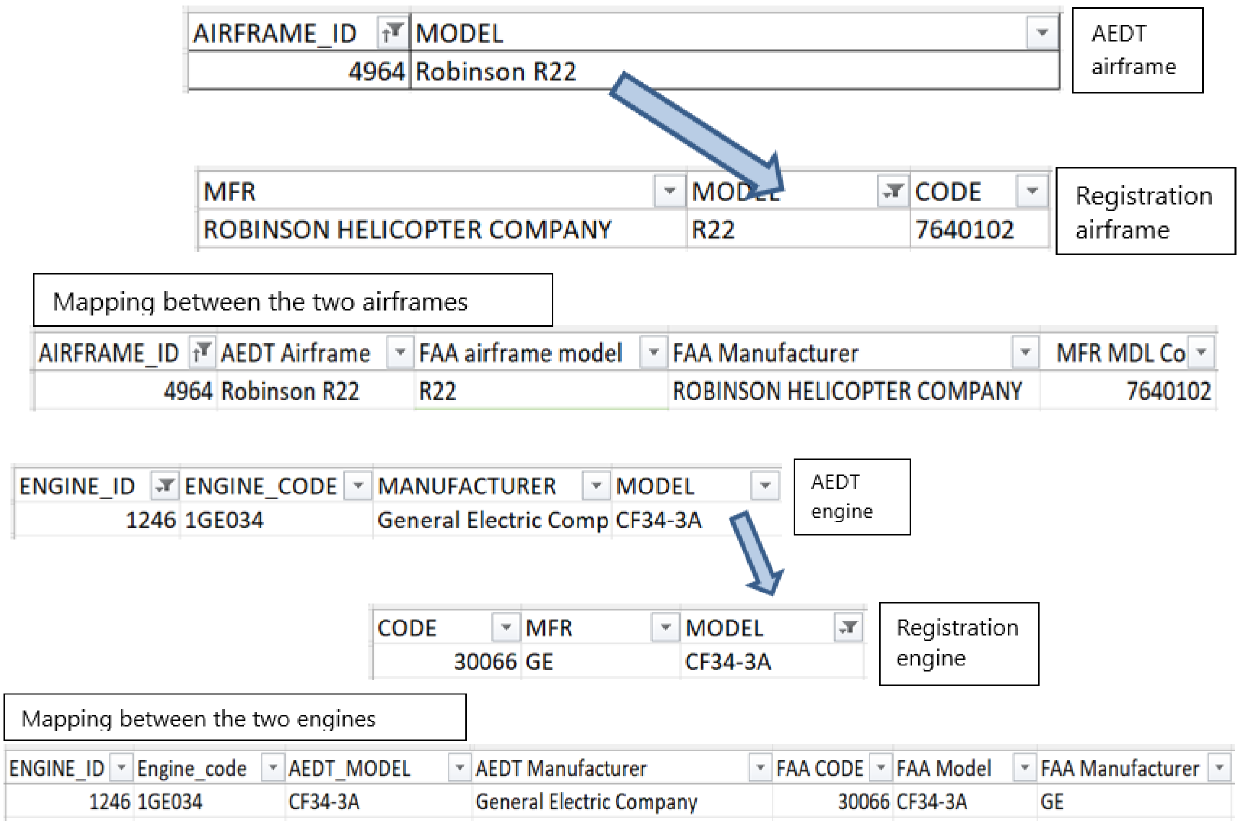

Figure 9: Example of airframe and engine match by names

With the airframe and engine mappings, an AEDT airframe and engine are assigned to each registered aircraft that is covered by the mapping. However, as pointed out earlier, AEDT equipment is not an arbitrary combination of AEDT airframe and engine. Therefore, a registered aircraft with an assigned AEDT airframe and engine does not necessarily have corresponding AEDT equipment. A registered aircraft can be assigned AEDT equipment only if its assigned AEDT airframe and engine consist of AEDT equipment. Only about 33% of the registered aircraft with assigned airframes and engines have corresponding AEDT equipment. The percentage may not be high enough to create a reliable estimate of the fleet mix. In Step 2, the assignment of the AEDT airframe and engine will be adjusted to improve the AEDT equipment assignment.

Step 2: Improve the mapping between the registration records and AEDT equipment.

After step 1, registered aircraft are compiled into three groups:

A. Aircraft with AEDT equipment assigned.
B. Aircraft with an AEDT airframe assigned but no AEDT equipment assigned. There are two scenarios. The first one is that there is no assigned AEDT engine. The second one is that an AEDT engine is assigned but there is no AEDT equipment corresponding to the assigned airframe and engine.
C. Aircraft without an AEDT airframe assigned.

This study first assigns AEDT airframes to aircraft in group C.

For each aircraft (target aircraft) in group C, the registration data is used to find the aircraft (reference aircraft) from groups A and B that meet the following conditions:

- Has the same aircraft type (e.g., fixed wing single engine and rotorcraft) as the reference aircraft.
- Has the same aircraft category (e.g., land and sea) as the reference aircraft.
- Has the same engine type (e.g., piston and Turbofan) as the reference aircraft.
- Has the same number of engines as the reference aircraft.
- Has the same aircraft weight category as the reference aircraft.
- The number of seats is as close to that of the reference aircraft as possible.

The AEDT airframe of the reference aircraft is assigned to the target aircraft. Aircraft in group C with assigned AEDT airframes will be either in group A or B.

Then this study re-assigns AEDT engines to aircraft in group B (target aircraft) so that they can be assigned AEDT equipment. There are two scenarios:

- **Scenario 1:** the target aircraft's assigned AEDT airframe has been assigned to aircraft in group A (reference aircraft). In this scenario, the AEDT engine of the reference aircraft will be assigned to the target aircraft. If there are multiple AEDT engines available, then engines will be chosen based on their frequency in aircraft of group A.
- **Scenario 2:** the target aircraft's assigned AEDT airframe has not been assigned to any aircraft in group A. In this case, the AEDT engine that consists of AEDT equipment with the target aircraft's assigned aircraft will be assigned to the target aircraft. If there are multiple AEDT engines available to choose from, then an approach is employed that avoids underestimating emissions to select the engine. Specifically, for an engine, AEDT considers the emission rate

of three pollutants: CO, NO_X, and hydrocarbon at four flight modes: take off, climb out, approach, and idle.

Let J be the set of all engines available to choose from, and $ER_{i,p,m}$ be the emission rate of pollutant p at mode m for engine i. AEDT has the emission rate for four modes: approach, take off, climb-out, and idling.

For each available engine, the highest emission rate of all flight modes is used for each of the pollutants. Let $ER_{i,p} = max_m(ER_{i,p,m})$ be the highest emission rate of pollutant p for engine i of all flight modes (worst emission rate). Then for each engine, the following statistics are calculated:

$$N_i = \sum_p I_{i,p}, i \in J,$$

where $I_{i,p} = 1$ if $ER_{i,p} \geq ER_{j,p} \forall j \in J$; otherwise, 0. In other words, if the worst emission rate of pollutant p for engine i is the highest among all available engines, then $I_{i,p}$ is set to 1; otherwise 0. N_i is the count of pollutants for which engine i's worst emission is the highest among all available engines.

The engine that will be assigned to the aircraft meets the following condition.

$$k = \arg\max_{j \in J}(N_j).$$

In other words, the engine k assigned to the aircraft is the engine that has the highest number of pollutants for which the engine's worst emission rate is the highest among all available engines. This method is conservative in that engine k (i.e., the engine chosen) has the highest emission rates for the largest number of pollutants.

After step 2, about 94% of registered aircraft are assigned AEDT equipment.

The FAA's registration records with assigned AEDT equipment are available in Appendix A. Note that multiple registered aircraft can be assigned the same AEDT equipment.

The frequency of the AEDT equipment assigned to the FAA's registration is calculated from the mapping. The frequency data produced are provided in Appendix B.

4.3.2 Fleet Mix Estimation

An overview of the fleet mix development process is shown in Figure 10. From Table 27, most of the flight uses that require local flight operations are performed by single-engine aircraft. This suggests that itinerant and local LTOs could have a different fleet mix. Therefore, this study applies different approaches to developing a fleet mix for itinerant and local LTOs.

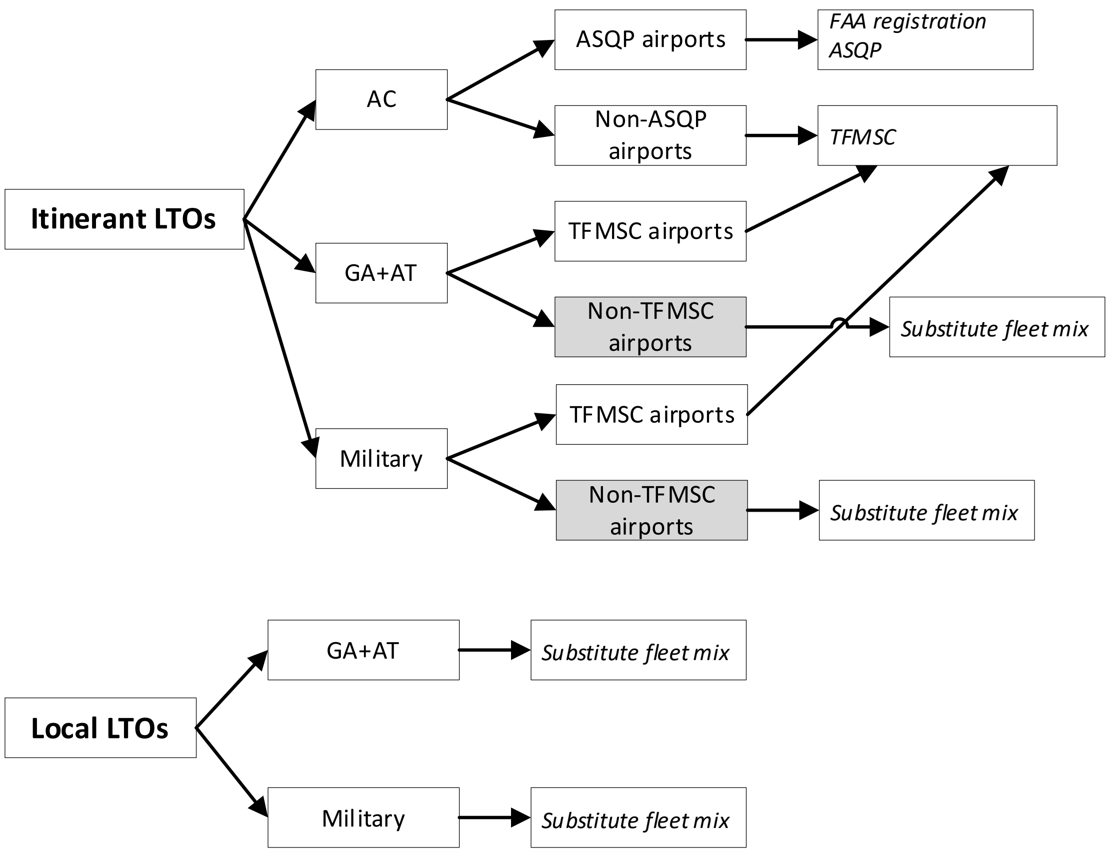

Figure 10: An overview of the fleet mix process

4.3.2.1 Air carrier LTOs

Air carrier LTOs are mostly itinerant. Almost all the landing facilities with a significant number of air carrier flight operations are covered by TAF and FAA's AMR, which means the LTOs by air carriers at these airports are estimated in levels 1 and 2 of the hierarchy method.

The following method is used to estimate the fleet mix of the LTOs by air carriers:

- For landing facilities that are covered by ASQP data, the fleet mix is estimated using ASQP data. Specifically, the record of the aircraft in each flight operation in the ASQP is located in the registration data using its N-number. The AEDT equipment assigned to its registration record is assigned to the aircraft.

- For landing facilities that are not covered by ASQP data but are covered by TFMSC data, the fleet mix is estimated using TFMSC data in a way similar to the one used in the prior study to devlop TCEQ's 2020 Airport AERR EI.

Table 34: Fleet Mix Development for Air Carrier LTOS by Landing Facility Category

Facility Category	ASQP	TFMS
Commercial*	24	1
Reliever	0	12
TASP	1	3

* Skylark Field Airport (ILE) has 0 LTOs by the air carrier in TAF

4.3.2.2 Itinerant GA and AT LTOs

The following methods are used to estimate the fleet mix of the itinerant GA and AT LTOs:

- **TFMSC** - For landing facilities that are covered by TFMSC data, the fleet mix is estimated using TFMSC data in a way similar to the one used in the prior study to devlop TCEQ's 2020 Airport AERR EI2020 Airport AERR EI. Specifically, the percentage of AEDT equipment is first estimated from the flight operation counts using the data. Then the fleet mix is calculated by multiplying the estimated LTOs by the percentage.

- **Substitute** - For other facilities, a substitute fleet mix is created. Itinerant operations can be performed by all aircraft types. Aircraft (i..e, AEDT equipment) from each aircraft engine type (i.e., piston-engine, turboprop, and jet-engine) are selected based on their frequencies in the FAA's registration records with assigned AEDT equipment (in Appendix C). To produce the results in this report, AEDT equipment of each aircraft engine type is ranked by their frequencies in descending order and the top 5 aircraft are selected. The selected AEDT equipment is presented in Table 35. The LTOs are assigned to each AEDT equipment proportional to their frequencies. For heliports, only helicopters are used to develop the substitute fleet mix.

Table 35: Selected Aircraft (AEDT Equipment) for Creating a Substitute Fleet Mix

Frame ID	Airframe Name	Engine ID	Engine Name	Engine Type	Frequency
4658	Bombardier Challenger 600	2110	CF34-3B/-3B1	J	1,699
4682	Cessna 525 CitationJet	1292	JT15D-1 series	J	1,552
4683	Cessna 550 Citation II	1293	JT15D-4 series	J	672
4688	Cessna 560 Citation Excel	1668	PW530	J	665
4776	Dassault Falcon 200	1531	CF700-2D	J	636
4665	Cessna 150 Series	1593	O-200	P	20,445
4666	Cessna 172 Skyhawk	1594	O-320	P	16,935
4667	Cessna 182	1567	IO-360-B	P	16,110
5594	Piper PA-18-150 (FAS)	1594	O-320	P	12,355
4952	Piper PA-28 Cherokee Series	1567	IO-360-B	P	11,668
4960	Pilatus PC-12	1612	PT6A-67B	T	1,131
4669	Cessna 208 Caravan	1595	PT6A-114A	T	881
4636	Raytheon Super King Air 300	1609	PT6A-60A	T	820
5005	EADS Socata TBM-700	1633	PT6A-64	T	760
4642	Raytheon King Air 90	1596	PT6A-135A	T	700
5080	Robinson R44 Raven / Lycoming O-540-F1B5	1715	TIO-540-J2B2	P	1,938
5079	Bell 407 / Rolls-Royce 250-C47B	1339	250B17B	T	1,496
5178	Robinson R22B	1566	IO-320-D1AD	P	1,416
5264	Enstrom 280FX/F-28F	1715	TIO-540-J2B2	P	1,158
4920	Hughes OH-6 Cayuse	1339	250B17B	T	720

Table 36 summarizes the number of landing facilities to which each method is applied. The fleet mix of almost all commercial and reliever airports is developed using the TFMSC data. For most of the other landing facilities, a substitute fleet mix is developed.

Table 36: Fleet Mix Development for Itinerant GA and AT LTOs by Landing Facility Category

Facility Group	GA		AT	
	Substitue	TFMS	Substitue	TFMS
Commercial	0	26	0	24
Farm/Ranch	139	0	14	0
Medical	183	0	183	0
Other_PR_Airports	635	0	13	0
Other_PR_Heliports	346	0	85	0
Other_PU_Airports	81	13	13	1
Other_PU_Heliports	3	0	1	0
Reliever	0	25	1	20
TASP	116	115	7	24

4.3.2.3 Local GA and AT LTOs

ASQP and TFMSC usually do not contain many local flight operations. Therefore, a substitute fleet mix is created for all local LTOs. Based on Table 27, local operations are most performed by aircraft with piston or turboprop engines. Using the same frequency from the FAA's registration records with assigned AEDT equipment, the same approach as the one used to create a substitute fleet mix for itinerant GA and AT LTOs is applied here but with jet-engine aircraft excluded from the selection.

4.3.2.4 Military LTOs

Approaches similar to those used to create the itinerant and local LTOs are used to develop the fleet mix of military LTOs. Since there can be many local military flight operations by aircraft with jet engines for training purposes, aircraft with jet engines are included in the substitute fleet mix for local operations.

Table 37 summarizes the number of landing facilities by facility category to which each method is applied. The fleet mix for the majority of commercial and reliever airports was developed using the TFMSC data. For most of the other airports, a substitute fleet mix is used.

Table 37: Fleet Mix Development for Military LTOS by Landing Facility Category*

Facility Category	Substitute	TFMSC
Commercial	0	26
Medical	15	0
Military	16	1
Other_PR_Heliports	43	0
Other_PU_Airports	3	0
Reliever	3	19
TASP	21	56

*There are military LTOs at non-military landing facilities.

4.3.3 Validation

This subsection presents a validation of the LTOs, and fleet mix developed in this project with those provided by the Dallas Fort-Worth International Airport (DFWIA).

The TTI study team received flight data in the database of the flight management system of the DFWIA. Table 38 presents sample flight records in the database.

Table 38: Sample Flight Records from DFWIA Database

ID	Registration	Departure	Destination	Aircraft subseries	Engine subseries	Primary usage	AEDT ANP
17534626	N644NK	KFLL	KDFW	A320-232	V2527-A5SelectOne	P	A320-232
17534634	N9012	KMIA	KDFW	A319-115	CFM56-5B7/3 PIP	P	A319-131
17534670	N913NN	KLAX	KDFW	737-800	CFM56-7B26E	P	737800
17534701	BLJC	PANC	KDFW	747-8F	GEnx 2B67	F/C	7478
17534750	N363FR	KDEN	KDFW	A320-251N neo	LEAP 1A26	P	A320-232
17534831	N539UW	KPHX	KDFW	A321-231	V2533-A5SelectOne	P	A321-232
17534875	B2096	PANC	KDFW	777-200LRF	GE90 110B1L	F/C	7773ER
17534957	BLJC	KDFW	KLAX	747-8F	GEnx 2B67	F/C	7478
17535024	N307AS	KSEA	KDFW	737-900	CFM56-7B24E	P	737800
17535034	N771AN	SBGR	KDFW	777-200ER	Trent 892	P	777200
17535044	N807AA	SCEL	KDFW	787-8	GEnx 1B70 PIP II	P	7878R

P – Passenger, **F** - Freight, **C** – Cargo.

The flight data in the database is expected to have good coverage of the LTOs and fleet mix at the DFWIA. The data contains information such as flight departure/arrival airports, aircraft registration number, and aircraft frame/engine. Each record is assigned an AEDT Aircraft Noise and Performance (ANP) profile ID. In AEDT, an ANP profile describes the movement of an aircraft in terms of aircraft state characteristics (e.g., altitude, speed, flap setting, and thrust). Each AEDT equipment is associated with an ANP profile ID, which is used by AEDT to estimate the equipment's emissions and noise.

The LTOs and fleet mix at the DFWIA are compared between those estimated in this study with those provided by the DFWIA, as shown in Table 39. The comparison is focused on the LTOs by ANP as the fleet mix in the DFWIA database were provided in terms of ANP.

Table 39: Summary Statistics of the Comparisons

	LTOs	Unique ANP	ANP in common
2019			
Current study	351,580	85	51
DFWIA database	357,248	71	51
Difference	-1.59%	19.72%	
2020			
Current study	279,659	72	44
DFWIA database	254,636	67	44
Difference	9.83%	7.46%	

Table 40 and Table 41 compare the summary statistics between the two datasets for 2019 and 2020, respectively.

Table 40: Comparison for 2019 LTOs and Fleet Mix

AEDT ANP ID	LTOs (current study)	LTO Percentage (current study)	LTOs (DFWIA database)	LTO Percentage (DFWIA database)	Cumulative percentage (DFWIA database)	LTO Difference
737800	75,276	21.41%	83,985	23.51%	23.51%	-10.37%
CRJ9-ER	39,904	11.35%	56,275	15.75%	39.26%	-29.09%
A321-232	42,854	12.19%	44,304	12.40%	51.66%	-3.27%
EMB170	31,838	9.06%	39,553	11.07%	62.74%	-19.51%
EMB14L	30,683	8.73%	33,836	9.47%	72.21%	-9.32%
A319-131	18,400	5.23%	25,401	7.11%	79.32%	-27.56%
MD83	13,830	3.93%	13,756	3.85%	83.17%	0.54%
A320-232	6,988	1.99%	12,662	3.54%	86.71%	-44.81%
757RR	1,234	0.35%	7,513	2.10%	88.82%	-83.58%
7878R	2,192	0.62%	5,769	1.61%	90.43%	-62.00%

Table 41: Comparison for 2020 LTOs and Fleet Mix

AEDT ANP ID	LTOs (current study)	LTOs Percentage (current study)	LTOs (DFWIA database)	LTOs Percentage (DFWIA database)	Cumulative percentage (DFWIA database)	LTO Difference
737800	59,055	21.12%	58,631	23.03%	23.03%	0.72%
CRJ9-ER	34,005	12.16%	40,648	15.96%	38.99%	-16.34%
EMB170	34,894	12.48%	38,621	15.17%	54.16%	-9.65%
A321-232	29,170	10.43%	28,380	11.15%	65.30%	2.78%
A319-131	23,608	8.44%	26,589	10.44%	75.75%	-11.21%
EMB14L	24,917	8.91%	24,763	9.73%	85.47%	0.62%
A320-232	3,673	1.31%	6,446	2.53%	88.00%	-43.02%
CNA208	79	0.03%	4,943	1.94%	89.94%	-98.40%
757RR	884	0.32%	4,195	1.65%	91.59%	-78.93%
7878R	1,594	0.57%	4,169	1.64%	93.23%	-61.77%

For 2019, the estimated number of LTOs in this project is about 1.6% fewer than the number in the DFWIA database. The number of unique ANPs in this project is about 20% more than the number provided in the DFWIA. The two datasets have 51 unique ANPs in common. For 2020, the estimated number of LTOs and ANP in this project is about 10% and 8% more than the number in DFWIA, respectively. The two datasets have 44 unique ANPs in common.

The ANP IDs are ranked by their LTOs from the DFWIA database and the top 15 are considered in the comparison. The combined LTOs of these 15 ANPs cover more than 95% of the total LTOs at the DFWIA. Tables 42 and 43 present the comparison for 2019 and 2020, respectively. Both the ANP IDs' LTOs and their LTO percentages are relatively close. The difference in the LTO increases as an ANP ID's LTO percentage decreases. However, the impact of the increasing difference is not expected to be high due to their relatively low LTO percentages.

4.3.4Summary Statistics of Fleet Mix

This subchapter presents a comparison of summary statistics between the fleet mix used in the 2020 Airport AERR EI and the current one. The fleet mix of LTOs for all Texas landing facilities developed in this study are provided in Appendix D.

Table 42 summarizes the comparison of the distribution of LTOs by user class. In the current fleet mix, the percentage of LTOs by AC is about half of the one in the previous fleet mix while the percentages of LTOs by the other user classes are higher. The main reason is as follows. This study not only develops the total LTOs but also estimates the LTOs by user class and develops a fleet mix for each user class separately. In contrast, the previous study estimates LTOs by user class using the TFMSC data. However, TFMSC data contains few local GA and AT flights, which could result in an underestimate of the percentage of LTOs by GA, AT, and military LTOs.

Table 42: Comparison of the Distribution of LTOs by User Class

User class	LTOs (Current studystudy)	Percent	LTOs (2020 Airport AERR EI)	Percent
AC	815,890	15.9%	1,392,015	30.1%
AT	271,693	5.3%	109,971	2.4%
GA	3,263,192	63.8%	2,734,981	59.1%
Mil	765,947	15.0%	391,104	8.5%

Table 43 presents the comparison of the distribution of LTOs by engine type. In the current study fleet mix, the percentage of LTOs by aircraft with the jet engine is about 10% lower than one in the previous study fleet mix while the percentage of LTOs by aircraft with piston engines is about 10% higher. The main reason is as follows. This study develops the fleet mix of local LTOs separately from the fleet mix of itinerant LTOs. As pointed out earlier, the majority of local LTOs are performed by aircraft with piston engines.

Table 43: Comparison of the Distribution of LTOs by Engine Type

Engine Type	LTOs (Current studystudy)	Percent	LTOs (2020 Airport AERR EI)	Percent
J	1,872,422	36.6%	2,080,508	45.0%
P	2,246,064	43.9%	1,585,582	34.3%
T	998,236	19.5%	961,981	20.8%
Total	5,116,722	100%	4,628,070	100%

4.4 Taxi Times and GSE/APU

Based on the literature review conducted in Task 3, the FAA's ASPM data is the best source to develop taxi times. For airports that are not covered by ASPM data, the TTI study team used the AEDT default taxi times. Similarly, the study team found that there is little regularly collected and publicly available data to develop estimates of GSE/APU usage for landing facilities in Texas. Therefore, we recommend that AEDT defaults are used for GSE/APU usage.

5 ASSESSMENT OF EMISSION IMPACT

This chapter covers the tasks that the TTI study team performed for this study under Task 5 - Assessment of Emissions Impact. This task required the study team to conduct an EI analysis comparing each of the updated airport activity AEDT input files developed from Task 4 with the corresponding input files used in TTI's most recent 2020 airport AERR EI and the 2020 Airport AERR EI trend EI project, PGA 582-21-11196-018 (Venugopal & Bibeka, 2021), for a select group of airport facilities. The results of this analysis identified which AEDT input parameters have the greatest potential impact on final emissions estimates.

Under Task 5, the major accomplishments are:

1. Automated the process of generating inputs for the AEDT to calculate emissions for all of the landing facilities considered in the airport EI.
2. Conducted a sensitivity analysis of emissions estimates per LTO for six criteria pollutants for several key input variables and identified input variables that could potentially have a significant impact on the overall emissions estimates. The major findings are:
   - Engine models, profile stage length (the distance between the take off airport and landing airport), taxi-out times, and taxi-in times could have a considerable impact on the overall emissions estimates.
   - APU time and runway length could have a minor or mild impact on the overall emissions estimates.
3. Calculated the EI for 2019 and 2020 using the aircraft activity (i.e., LTOs, and the associated fleet mix) developed in this project. Compared the emissions of criteria pollutants estimated in this project with those from the 2020 Airport AERR EI. The comparison shows the emissions of total VOC, PM ($PM_{2.5}$ and PM_{10}), CO, and Pb emissions estimated in this project are between 20-30% higher, respectively. The estimates of total NO_x and SO_2, on the other hand, are 22% and 8% lower, respectively. Note that in any future airport EI development, the TTI study team will develop the estimates of LTOs and fleet mix for all landing facilities in Texas using the methods and procedures presented in Task 4 of this project. However, as pointed out early in the report, landing facilities are the best sources to obtain accurate aicraft activity data. For landing facilities that provide satisfactory activity data, the TTI study team may use their activity data instead.
4. In the 2020 Airport AERR EI, three commercial airports in the Houston Airport System (HAS) provided their aircraft activity and associated EI (Parise & Pringle, 2021) to the TTI study team. To help determine the cause of the differences in EI

calculation between this project and 2020 Airport AERR EI, the TTI study team compared the emissions estimates of individual AEDT equipment from the three airports with those estimated in this task. These comparisons show that the differences in the emissions estimates are largely caused by the differences in the estimates of the fleet mix (i.e., airframes and engine models of the LTOs).

The rest of this chapter is organized as follows. The following subchapter introduces the automation process of generating inputs for AEDT. Next, the study team describes the sensitivity analysis. Subsequently, the next sub-chapter compares the emission estimates at commercial and reliever airports between this task and those in the 2020 Airport AERR EI. Finally, this chapter concludes with a summary.

5.1 Generating Complete AEDT Standard Input Files

The AEDT Standard Input File (ASIF) provides a standard file format to allow for the import of data into AEDT. The ASIF is in the extensible markup language (XML) text-based file format. Data values are tagged with elements and organized in a hierarchical manner such that the elements can contain other elements or data. The ASIF format allows users to create a new study[7] (model run specification) by importing an XML file that includes information on airports, scenarios, cases, operations, tracks, and other study definitions. Users can also use the partial ASIF to import data into an existing AEDT study.

In the 2020 Airport AERR EI, a study for an airport EI was first manually created via the AEDT user interface. Then a partial ASIF was developed and imported into AEDT to create a complete study for the AEDT to compute emissions estimates. This process is time-consuming, which restricts the number of studies that can be created depending on the schedule.

In this task, the TTI team automated the process of creating a study for an airport EI in the AEDT by developing a complete ASIF for the study. The significance of this work is that the TTI team can now develop studies for AEDT for all the landing facilities in Texas within hours.

[7] A study is a term used in AEDT. An AEDT study is the setup for an AEDT model run. For airport EI, it means a setup that contains all the necessary information for the AEDT to compute the emission estimates. An AEDT study contains at least one airport. In this task, TTI includes hundreds of airports in one AEDT study.

The rest of this section will present the development of some key input variables for the study and the creation of ASIFs.

5.1.1 Selection of Airport Runway

AEDT requires a runway for each LTO. This task uses the airport runways in the AEDT database for emissions analysis. Figure 11 shows seven runways and one helipad at the Dallas-Fort Worth International airport (DFWIA). For a landing facility with multiple runways, the longest runway is used. For cases where a runway or helipad is not available in the AEDT database, this task creates a runway with a runway length of 2,000 ft for fixed-wing aircraft and 180 ft for rotorcraft.

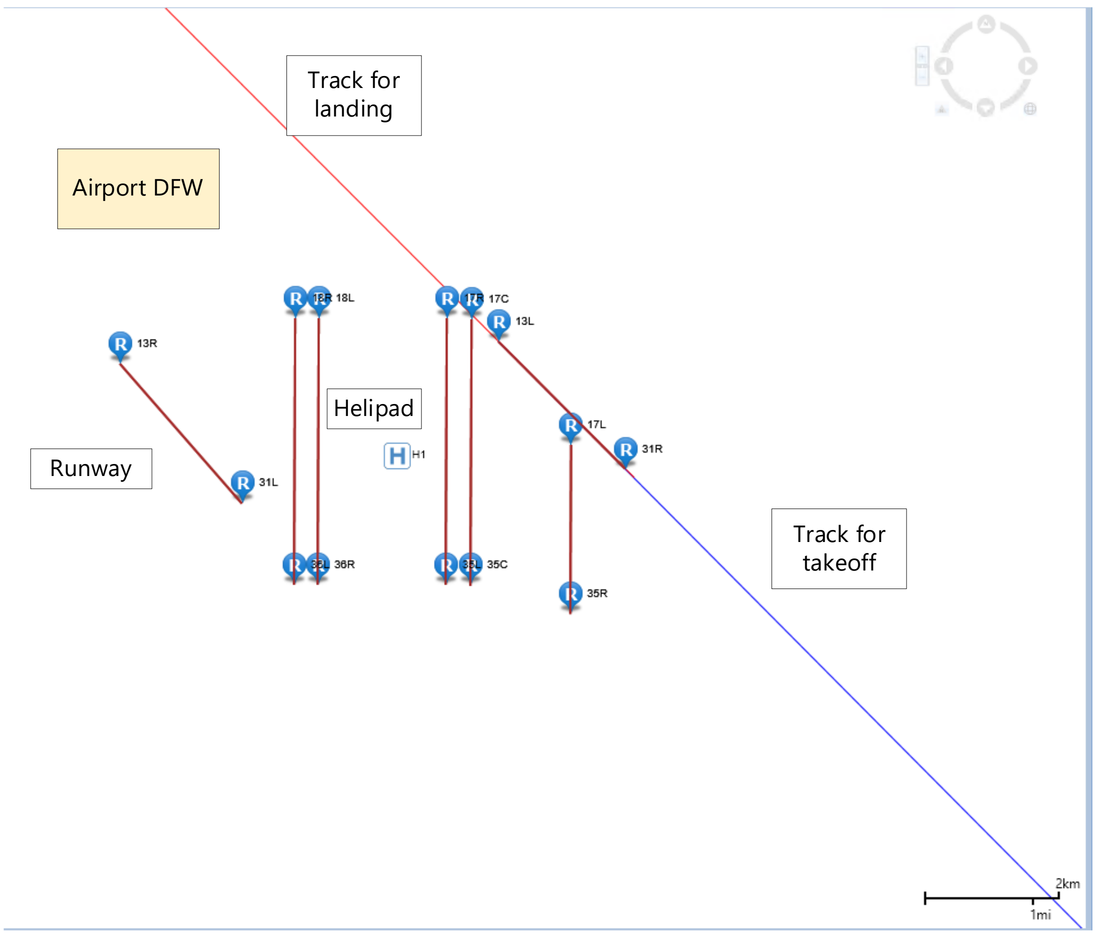

Figure 11: Layout for the DFWIA

5.1.2 Creating Runway Track

In addition to a runway, tracks are also required for both landing and take off operations. A track is a two-dimensional path (e.g., a sequence of latitude and longitude points) for an aircraft to follow when it is not on the runway, but rather when it is in flight descending to the runway (track for landing) and after take off (track for take off). The aircraft's altitude along the track will be determined by its take off or landing profiles. This task follows the AEDT's practice to create tracks. Specifically, as shown in Figure 12, for take off operations, the track is created by extending the starting point of the take off on the selected runway along the direction of the take off operation by 116,000 ft (about 20 nautical miles).

Figure 12: Runway track for take off operations

Similarly, as illustrated in Figure 13, the track for the landing operation is created by extending the touch-down point of the landing operation on the selected runway along the opposite direction of the landing operation by 116,000 ft.

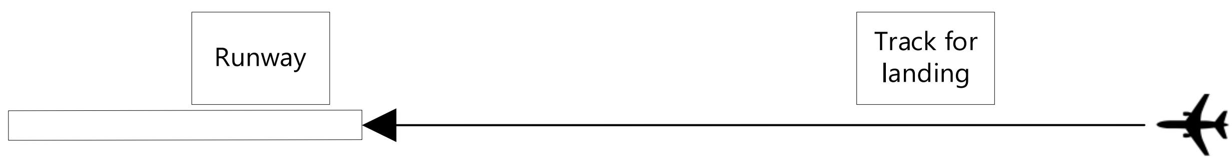

Figure 13: Runway track for landing operations

The tracks for take off and landing operations at runway 13L-31R at DFWIA are shown in Figure 11.

5.1.3 Aircraft Take off and Landing Profile

A flight ANP profile describes the movement of an aircraft in terms of aircraft state characteristics (e.g., altitude, speed, flap setting, and thrust) as a function of horizontal distance over the ground (and in some cases for helicopters, time). A flight profile does not contain information about the lateral path an aircraft follows over the ground (the lateral path is described by a track). The AEDT can compute flight performance for a profile-driven operation according to the commonly used aircraft performance models. For more detailed information, refer to the FAA's AEDT Technical Manual [3].

Table 44 presents the built-in profile types selectable in the AEDT. This task uses the profile types STANDARD and NOISEMAP as the two types contain profiles for both arrival and departure operations. Some aircraft may have both profiles, in this case, priority is given to the STANDARD profile type. If an aircraft does not have any of the two profiles, then an aircraft that has a similar performance in terms of emission rates, engine type, and aircraft size, and has at least one of the profiles, will be used as a surrogate to generate emissions estimates. Most aircraft that need a surrogate aircraft are military aircraft.

Table 44: AEDT Profile Types

Profile Type	Profile Naming Convention	Comments
Default Profiles		
STANDARD	STANDARD	Departure, Approach, Circuit, or Touch and Go operations
NOISEMAP	NOISEMAP	Departure, Approach Military Aircraft Profiles
ICAOA	ICAO A, ICAO_A, ICAOA, ICAO-A	Departure operations only
ICAOB	ICAO B, ICAO_B, ICAOB, ICAO-B	Departure operations only
CNA206/CNA20T Specific	3000LB, 3300LB, 3600LB	Departure operations only
CNA510/CNA55B Specific	FLAPS_0, FLAPS_15	Departure operations only
CNA750 Specific	FLAP_5, FLAP_15	Departure and Approach operations
ECLIPSE500 Specific	HI_ALT	Departure operations only
GII/GIIB Specific	QF_FLEX, QF_FULL	Departure operations only

For more information, refer to the FAA's AEDT Technical Manual (FAA, 2021)

One profile type may consist of multiple profiles with different stage lengths and aircraft weights (for example, see Table 45). Similar to the approach the TTI used to develop the 2020 Airport AERR EI, this task adopts the profile with the longest stage length and highest aircraft weight. This conservative approach is used to avoid underestimating the emissions.

Table 45: Departure Profiles of the STANDARD Profile Type for the Boeing 767-300 Series with Engine Model 1PW043

Profile ID	Profile Name	Operation Type	Profile Type	Stage Length	Weight (lb.)
627	STANDARD	D	Procedural	1	265,000
628	STANDARD	D	Procedural	2	275,500
629	STANDARD	D	Procedural	3	286,400
630	STANDARD	D	Procedural	4	305,700
631	STANDARD	D	Procedural	5	330,000
632	STANDARD	D	Procedural	6	355,900
633	STANDARD	D	Procedural	7	367,700

5.1.4 Taxi-In and Taxi-Out Time

This task adopts the same taxi times as those used by the TTI to develop the 2020 Airport AERR EI. Taxi times from both ASPM and survey results were used for the commercial, reliever, and surrogate airports. Appendix E summarizes the landing facilities with the taxi times available in the 2020 Airport AERR EI and their default taxi times in the AEDT database. The averages of the taxi times used to develop the 2020 Airport AERR EI are close to the averages of AEDT default taxi times.

However, the taxi times from ASPM and surveys only covered a limited number of airports. For the landing facilities whose taxi times are not available in ASPM or surveys, TTI proposes to use AEDT default taxi times.

5.1.5 APU and APU Time

For each AEDT equipment, this task uses its AEDT default APU model and the default APU time of 13 minutes for both take off and landing operations. This is the same as those used in the 2020 Airport AERR EI.

5.1.6 GSE and GSE Time

For each AEDT equipment, this task uses its AEDT default set of GSE models and usage (e.g., time). This is the same as those used in the 2020 Airport AERR EI.

5.1.7 Summary of ASIFs

The TTI study team produced ASIFs for all of the landing facilities in Texas. Appendix F describes the detailed workflow of the ASIF creation using Python. The ASIFs are included in Appendix G. However, due to an issue in the AEDT's airport database, the ASIFs for some landing facilities cannot be imported into AEDT. The AEDT technical support suggested a manual process to create studies for these airports in AEDT. The TTI study team decided not to implement the manual process in this project as it is time-consuming and inconsistent with the primary goals of this project. Table 46 summarizes the number of landing facilities whose ASIFs (valid ASIF) can be imported into AEDT by facility category and their percentage in the category. More than 83% of the landing facilities have a valid ASIF. Particularly, almost all the facilities in the commercial, reliever, and TASP categories have a valid ASIF.

Table 46: Number and Percentage of Facilities with Valid ASIFs by Facility Category

Facility Category	Number of facilities have a valid ASIF	Total facilities	Percentage
Commercial	26	26	100.00%
Farm/Ranch	376	464	81.03%
Medical	162	186	87.10%
Military	15	20	75.00%
Other Private Airports	531	674	78.78%
Other Private Heliports	290	349	83.09%
Other Public Airports	84	97	86.60%
Other Public Heliports	0	3	0.00%
Reliever	24	25	96.00%
TASP	221	231	95.67%
Total	**1,729**	**2,075**	**83.33%**

To estimate the emissions from the LTOs on a facility with an invalid ASIF, this task proposes the following two possible approaches:

1. For each aircraft using the facility, estimate its average emissions per LTO (emission rate) using its emissions results at the facilities with valid ASIF. Then, calculate its emissions at the facility by multiplying the emissions rate by its LTOs.
2. Move the LTOs to a similar facility that has a valid ASIF and estimate the emissions directly using AEDT.

5.2 Sensitivity Analysis

This section describes a sensitivity analysis of the emissions estimates in response to the following key variables: engine model, profile, runway length, track length, APU time, and taxi times.

Selecting aircraft and landing facilities for the sensitivity test was challenging as the AEDT does not offer sufficient variations on some of the variables. For example, some of the most commonly used piston aircraft have only one profile in AEDT and most GA landing facilities have only one runway or multiple runways with similar lengths.

This task selected the Boeing 767-300 Series with engine model 1PW043 at the DFWIA to conduct the sensitivity analysis. The Boeing 767-300 Series has a large number of LTOs at commercial airports. In addition, its airframe can be equipped with multiple engine models in the AEDT. The DFWIA has 7 runways as shown in Figure 11 above; more information for the 7 runways is available in Table 47. The longest runway at the airport is 13,401 feet and the shortest one is 8,500 feet. According to 2019 data in ASPM, the annual average taxi-out and taxi-in times at the DFWIA are 17.12 minutes and 10.6 minutes, respectively.

Table 47: Available Runways at the DFWIA

Length	Width	Taxi-Out Min	Tax-In Min	Runwayend ID 1 Name	Runwayend ID 2 Name
9,000	200	17.12	10.6	13L	31R
9,301	150	17.12	10.6	13R	31L
13,401	150	17.12	10.6	17C	35C
8,500	150	17.12	10.6	17L	35R
13,401	200	17.12	10.6	17R	35L
13,400	200	17.12	10.6	18L	36R
13,400	150	17.12	10.6	18R	36L

5.2.1 Variables Tested

Using the Boeing 767-300 Series with engine model 1PW043 at the DFWIA, sensitivity testing on six variables (engine model, profile, runway length, track length, APU time, and taxi times) was performed. For each AEDT sensitivity test run, an ASIF was created by changing one of the variable values as detailed in the following subsections.

5.2.1.1 Engine Model

In the AEDT, equipment is defined as the combination of airframe and engine model. The same airframe can be equipped with different engine models to create different equipment in the AEDT. For each airframe, this task tests the sensitivity of emissions estimates for different engine models. Specifically for this task, the TTI study team calculated and compared the emission results of each engine model that the airframe of the Boeing 767-300 Series can be equipped with.

5.2.1.2 Profiles

As discussed earlier, an aircraft could have multiple profiles under one profile type. This task chose the profile with the longest stage length (highest aircraft weight). As more emissions are produced during the taking-off operation, the emissions of two cases for the departure profiles were tested. The first case used the departure profile with the longest stage length (used to create the ASIF), while the other case used the departure profile with the shortest stage length.

Table 48 shows the two departure profiles for the Boeing 767-300 Series with engine model 1PW043 used in the sensitivity test.

Table 48: Departure Profiles for the Boeing 767-300 Series with Engine Model 1PW043 Used in Sensitivity Testing

Case	Stage Length	Weight (lb.)
1	7	367,700
2	1	265,000

5.2.1.3 Runway Length

For runway length, two cases were tested, as listed in Table 49. The first case used the longest runway, while the other case used the shortest runway.

The longest runway at the DFWIA airport is 17C-35C whereas the shortest runway is 17L-35R.

Table 49: DFWIA Runway Lengths Used in Sensitivity Testing

Case	Runway length (feet)
1	13,401
2	8,500

5.2.1.4 Track Length

For track length, two cases were tested, as listed in Table 50. The first case used a track with 116,000 feet (19 nautical miles), while the other case used a track with 303,800 feet (50 nautical miles).

Table 50: Track Lengths Used in Sensitivity Testing

Case	Track length (feet)
1	116,000
2	303,800

5.2.1.5 APU Time

Three cases were tested for the APU time, as listed in Table 51. The first case is 13 minutes. The second case reduced the APU time in the first case by half (6.5 minutes), while the third case doubled the APU time in the first case (26 minutes).

Table 51: APU Times Used in Sensitivity Testing

Case	APU time (minutes)
1	13
2	6.5
3	26

5.2.1.6 Taxi Time

Three cases were tested for the taxi times, as listed in Table 52. In the first case, the taxi times from the ASPM were used; for the DFWIA airport, the taxi-out and taxi-in times were 17.12 minutes and 10.6 minutes, respectively. The second case reduced the taxi times in the first case by half (8.56 minutes and 5.3 minutes for taxi-out and taxi-in times, respectively), while the third one doubled the taxi times in the first case (34.24 minutes and 21.2 minutes for taxi-out and taxi-in times, respectively).

Table 52: Taxi-out and Taxi-in Times Used in Sensitivity Testing

Case	Taxi-out time (minutes)	Taxi-in time (minutes)
1	17.12	10.6
2	8.56	5.3
3	34.24	21.2

5.2.2 Summary of Scenarios

A scenario is defined using case numbers of the variables given in Table 47 through Table 52. All the scenarios in the sensitivity test are summarized in Table 53. For example, in the baseline scenario, the aircraft is equipped with engine model 1PW043 and uses the longest runway, track length, departure stage length; and middle time durations for APU, taxi-out, and taxi-in times. The baseline scenario represents the current practice used in this task to generate the EI using AEDT. There are eight alternative scenarios, each using a different variable in place of one of the key variables (e.g., engine model, runway length, etc.) used in the current practice. The emissions estimates in the alternative scenarios are compared to those in the baseline scenario to determine the sensitivity of the key variables.

Table 53: Baseline and Alternative Scenarios for Sensitivity Analysis of the Boeing 767-300 Series at the DFWIA Airport

Scenario	Engine model	Runway length	Track length	Departure profile	APU time	Taxi time
Baseline	1PW043	1	1	1	1	1
Alternative 1	49 engine models	1	1	1	1	1
Alternative 2	1PW043	2	1	1	1	1
Alternative 3	1PW043	1	1	2	1	1
Alternative 4	1PW043	1	2	1	1	1
Alternative 5	1PW043	1	1	1	1	2
Alternative 6	1PW043	1	1	1	1	3
Alternative 7	1PW043	1	1	1	2	1
Alternative 8	1PW043	1	1	1	3	1

The numbers 1, 2, and 3 in the runway length through taxi time columns are Case numbers as shown in Table 5 through Table 9 above.

5.2.3 Results Analysis

Table 54 presents the estimates of fuel consumption, and VOC, NO_x, PM ($PM_{2.5}$ or PM_{10}), and CO emissions for the baseline and alternative 1 scenarios with selected engine models during aircraft take-off operations until mixing height[8] is reached. The first row

[8] The height of the atmosphere where relatively vigorous mixing of pollutants and other gases takes place. Directly above the mixing height, the atmosphere is stable, and there is limited upward dispersion of polluted air. The mixing height varies both diurnally and seasonally. A mix height of 3000 feet is used in this task.

of the table shows the emissions estimates for the baseline scenario. The other table rows show the emissions estimates for the 24 other possible engine models considered in the sensitivity analysis, along with the percentage difference in emissions estimates compared to the baseline scenario.

Table 54: Emission Estimates per LTO (in short ton) for the Baseline and Alternative 2 Scenarios with Different Engine Models

Engine Model	Fuel	Diff.	VOC	Diff.	NO_x	Diff.	PM_{25} (PM_{10})	Diff.	CO	Diff.
1PW043	**1.21**		**1.71E-03**		**0.024**		**2.50E-04**		**1.30E-02**	
1GE012	1.07	-11.8%	3.53E-03	106.4%	0.022	-9.5%	2.60E-04	4.0%	1.32E-02	1.5%
1GE020	1.20	-1.1%	5.92E-03	246.2%	0.024	0.8%	2.70E-04	8.0%	2.34E-02	80.1%
1GE025	1.17	-3.9%	6.68E-03	290.6%	0.018	-23.9%	2.60E-04	4.0%	2.49E-02	91.7%
1GE026	1.15	-5.2%	6.79E-03	297.1%	0.018	-25.2%	2.60E-04	4.0%	2.49E-02	91.7%
1GE027	1.18	-2.6%	6.13E-03	258.5%	0.022	-9.9%	2.70E-04	8.0%	2.37E-02	82.4%
1GE028	1.17	-3.8%	6.30E-03	268.4%	0.022	-10.3%	2.60E-04	4.0%	2.39E-02	84.0%
1GE029	1.20	-1.1%	5.92E-03	246.2%	0.023	-7.0%	2.70E-04	8.0%	2.34E-02	80.1%
1GE030	1.18	-3.1%	6.07E-03	255.0%	0.023	-3.7%	2.70E-04	8.0%	2.34E-02	80.1%
1PW022	1.23	1.1%	1.67E-02	877.8%	0.033	37.9%	2.90E-04	16.0%	3.11E-02	139.4%
1PW026	1.20	-1.4%	1.43E-03	-16.4%	0.029	18.6%	2.30E-04	-8.0%	6.88E-03	-47.0%
1PW027	1.23	1.5%	1.42E-03	-17.0%	0.031	27.6%	2.30E-04	-8.0%	6.95E-03	-46.5%
1PW030	1.29	6.0%	1.78E-03	4.1%	0.032	33.4%	2.60E-04	4.0%	9.55E-03	-26.4%
1PW032	1.27	4.7%	1.69E-02	889.5%	0.033	35.9%	2.70E-04	8.0%	4.13E-02	218.0%
1PW041	1.16	-4.7%	1.12E-03	-34.5%	0.024	0.8%	2.80E-04	12.0%	7.46E-03	-42.5%
1PW042	1.20	-0.9%	1.79E-03	4.7%	0.022	-9.5%	2.40E-04	-4.0%	1.35E-02	3.9%
1PW053	1.17	-3.7%	4.35E-03	154.4%	0.020	-18.6%	2.50E-04	0.0%	1.98E-02	52.4%
1PW054	1.18	-2.8%	4.03E-03	135.7%	0.021	-14.4%	2.40E-04	-4.0%	1.91E-02	47.0%
1PW055	1.20	-0.9%	3.47E-03	102.9%	0.023	-4.5%	2.40E-04	-4.0%	1.76E-02	35.4%
1PW056	1.21	0.0%	3.28E-03	91.8%	0.024	0.0%	2.40E-04	-4.0%	1.70E-02	30.8%
1PW058	1.22	0.7%	1.67E-03	-2.3%	0.026	5.8%	2.50E-04	0.0%	1.27E-02	-2.3%
1RR011	1.32	8.8%	1.50E-03	-12.3%	0.045	85.4%	3.10E-04	24.0%	9.99E-03	-23.0%
2GE039	1.19	-1.5%	1.55E-03	-9.4%	0.021	-11.5%	2.20E-04	-12.0%	1.15E-02	-11.2%
2GE042	1.16	-4.3%	1.71E-03	0.0%	0.018	-27.6%	2.10E-04	-16.0%	1.25E-02	-3.9%
2GE043	1.19	-2.2%	1.58E-03	-7.6%	0.020	-16.5%	2.20E-04	-12.0%	1.18E-02	-9.5%

The information in **bold** is for engine model 1PW043 or the baseline scenario; the "Diff" column tracks the difference in emissions estimates of the various engine models to 1PW043.

The following major observations were made:

- Engine models have a significant impact on emissions estimates. For example, engine model 1PW032 produces about 890% more VOC, 35% more NOx, 8% more PM, and 220% more CO than engine model 1PW043.
- Different engine models have different pollutant emitting qualities and there is no trend to be inferred. For example, engine model 1PW026 produces more NO_x but less VOC, PM, and CO than 1PW043 (baseline scenario) while engine model 1PW054 produces more VOC and CO but less PM and NO_x than 1PW043.
- Emissions estimates are not always positively correlated with fuel consumption. For example, engine model 1PW027 consumes 1.5% more fuel than 1PW043 (baseline scenario) but produces 17% less VOC and 47% less CO.

Due to the complexity of aircraft engines, it is challenging to fully explain the observations within this task. However, these observations highlight the importance and challenges of selecting appropriate engine models to estimate airport EIs.

In the 2020 Airport AERR EI, TTI prioritized the use of the fleet mix information provided by airports. For example, TTI directly used the fleet mix and EI information developed for the three airports in the HAS study. For the landing facilities where fleet mix information is not provided, engine models were selected almost randomly to achieve thorough coverage; comparatively, in this task, fleet mix information was estimated by using the FAA's registration data and airport-level flight operations data. These data sources provide detailed information about individual aircraft, such as their airframe and engine model. Thus, for landing facilities that did not provide information on their fleet mix in the 2020 Airport AERR EI, the selection of engine models in this task is more accurate. In cases where no information from FAA's registration data could be used to select engine models for an airframe, the TTI team selected the engine model that had the worst overall emissions to produce conservative emissions estimates.

Table 55 summarizes the fuel consumption, distance required, and the estimated VOC, NO_x, PM, and CO emissions for the baseline scenario and alternative scenarios 2 through 8 during aircraft take-off operations till reaching mixing height.

Table 55: Annual Emission Estimates per LTO (Short Ton) for Alternative Scenarios 2 through 8

Scenario name	Fuel	Dist. (mi)	VOC	NO_x	PM	CO
Baseline	**1.21**	**7.6**	**1.71E-03**	**2.43E-02**	**2.50E-04**	**1.30E-02**
Alt 2	1.23	7.68	1.71E-03	2.48E-02	2.50E-04	1.30E-02
Alt 3	0.96	4.39	1.69E-03	1.68E-02	2.10E-04	1.28E-02
Alt 4	1.21	7.6	1.71E-03	2.43E-02	2.50E-04	1.30E-02
Alt 5	0.97	7.6	1.21E-03	2.30E-02	1.90E-04	7.62E-03
Alt 6	1.70	7.6	2.69E-03	2.63E-02	3.00E-04	2.34E-02
Alt 7	1.21	7.6	1.71E-03	2.41E-02	2.30E-04	1.29E-02
Alt 8	1.21	7.6	1.73E-03	2.45E-02	2.70E-04	1.31E-02
Percentage Difference between baseline and alternative scenarios						
Alt 2	1.5%	1.1%	0.0%	2.1%	0.0%	0.0%
Alt 3	-21.2%	-42.2%	-1.2%	-30.9%	-16.0%	-1.5%
Alt 4	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Alt 5	-19.9%	0.0%	-29.2%	-5.1%	-24.0%	-41.3%
Alt 6	39.8%	0.0%	57.3%	8.5%	20.0%	80.4%
Alt 7	0.0%	0.0%	0.0%	-0.6%	-8.0%	-0.5%
Alt 8	0.0%	0.0%	1.2%	1.1%	8.0%	0.9%

The information in **bold** is for the baseline scenario.

In the Alternative 2 scenario, the shortest runway was used. The result shows that it took the longest distance among all scenarios for the aircraft to reach the mixing height. The fuel consumption and NO_x emissions are slightly higher than the baseline scenario. The TTI team believes this could be due to the lower vertical speed after the aircraft leaves the runway.

In the Alternative 3 scenario, the shortest stage length (the distance between the take off airport and landing airport) and lowest take-off weight are used. As a result, it takes 42% less distance and 21% less fuel to reach the mixing height. Similarly, the emissions of NO_x and PM are also significantly lower.

In the Alternative 4 scenario, a longer track than the baseline scenario track was used. The estimated fuel consumption, the distance needed, and emissions were the same as those in the baseline scenario. The TTI team believes that this suggests track length has no significant impact on emissions estimates.

In the Alternative 5 scenario, taxi times were reduced to half of the baseline scenario. The fuel consumption decreased by about 20%, while the emissions decreased by about

30% for VOC, 5% for NO_x, 24% for PM, and 41% for CO. However, in the Alternative 6 scenario, where taxi times were doubled, the fuel consumption increased by about 40% compared to the baseline scenario, while the emissions increased by about 57% for VOC, 8.5% for NO_x, 20% for PM, and 80% for CO. The TTI team believes that these two alternative scenarios show that taxi time is a crucial variable that directly impacts emissions estimates.

In the Alternative 7 scenario, APU usage time was reduced to half. Except for the PM, there were no significant decreases in the other emissions nor in fuel consumption. In the Alternative 8 scenario, where APU usage time was doubled, except for the PM, there were no significant increases in both fuel consumption and the emissions of other pollutants. Based on the observations, APU usage time appeares to be a significant variable in afffecting only the emissions of PM from aircraft.

In summary, the following conclusions were made based on the sensitivity analysis.

1. An accurate selection of engine models is important as the emissions results can be sensitive to the engine models used in the AEDT. In Task 4 of this project, the TTI study team improved the selection of engine models by using FAA's registration data. Further improvement should be made in future studies by, for example, using ADS-B data when applicable.

2. Some pollutants (NO_x and PM) may be sensitive to runway length; however, the majority of landing facilities considered in airport EIs have only one runway or do not have runways that differ significantly in length.

3. Profile stage length has a significant impact on emissions estimates. This task uses the longest stage length to generate conservative emissions estimates.

4. Taxi times have a significant impact on emissions estimates. This task uses the same taxi times as those used to develop the 2020 Airport AERR EI (specifically for DFWIA), which were developed based on the taxi times from ASPM and surveys.

5. APU usage time has a minor effect on the emissions of pollutants other than PM. However, since APU usage is usually limited to commercial operations, its impact on overall emissions totals could be limited.

6 EI DEVELOPMENT AND COMPARISON

This chapter covers the emissions impact assessment that the TTI study team performed for this study under Task 5 - Assessment of Emissions Impact.

In this section, the TTI study team compares the estimates of VOC, NO_x, PM, SO_2, CO, and Pb emissions from this task with those from the 2020 Airport AERR EI and HAS study. The studies used in the comparison summarizedbelow in Table 56.

Table 56: Summary of Studies Used in the Comparison

Name	Description
2020 Airport AERR EI	The study (Venugopal & Bibeka, 2021) calculated the EI for 2,037 landing facilities in 254 counties in Texas.
HAS study	The study (Parise & Pringle, 2021) developed the aircraft activity and EI for three airports: George Bush Intercontinental Airport (IAH), William P. Hobby Airport (HOU), and Ellington Airport (EFD). The EIs of the three airports are directly incorporated into the 2020 Airport AERR EI.
Current study	This project calculates the EIs for 2019 and 2020 using the LTOs and fleet mix developed in previous sections.

6.1 2019 EI AND 2020 EI DEVELOPED IN THIS PROJECT AND COMPARISON WITH THOSE FROM 2020 AIRPORT AERR EI

This subsection presents the 2019 and 2020 EI calculated in current study using the LTOs and fleet mix developed in this project.

Table 57 summarizes the major data sets and assumptions used to create inputs for the AEDT to calculate these EIs. Compared with 2019 taxi times, 2020 taxi times available to this project have a much smaller coverage. Since the EI is sensitive to taxi times, 2019 taxi times are used to calculate the 2020 EI. This would lead to a conservative EI as the taxi times in 2020 are expected to be lower due to lower demand. Since the AMR in 2019 and 2020 are not available, the AMR used (accessed in April 2022) for task 3 of this project is used for both EIs. In addition, since no improvements are made to estimate control strategies in this project, control strategies are not applied in the EI calculations.

Table 57: Summary of Inputs and Assumptions in current study 2019 and 2020 EI development

Inputs	2019 EI	2020 EI
TAF	2019 operations in TAF	2020 operations in TAF
Registration	2019 FAA's registration data	2020 FAA's registration data
Registration records mapped to AEDT equipment	Appendix B	Appendix B
ASQP	ASQP 2019	ASQP 2020
TFMSC	TFMS 2019	TFMSC 2020
TFMSC aircraft type mapped to AEDT airframe	Appendix B	Appendix B
GA survey	GA survey 2019	GA survey 2020
AMR	AMR accessed April 2022	AMR accessed April 2022
Taxi times	2019 taxi times	2019 taxi times
Control strategies	No control strategies	No control strategies
Software	AEDT 3D	AEDT 3D
Runway, APU, and GSE usage	Section 5.1	Section 5.1

The LTO data used in the 2020 Airport AERR EI (except for the airports in HAS) were estimated by applying growth factors to the 2019 LTO data. Therefore, the analysis and comparison in this section are focused on the 2019 EI. Table 58 comparise the LTOs by user class and engine type for the 2019 EI between the two studies.

Table 58: Comparison of LTOs by User Class and Engine Type for 2019 EI

User Class	Engine Type	2019 LTO (previous study)	2019 LTO (current study)	Difference
Commercial Aviation	J	1,119,435	809,772	-27.66%
Commercial Aviation	P	97,505	464	-99.52%
Commercial Aviation	T	175,074	5,654	-96.77%
Air Taxi	J	95,925	226,375	135.99%
Air Taxi	P	0	976	-
Air Taxi	T	14,045	44,342	215.71%
GA	J	655,391	391,401	-40.28%
GA	P	1,469,681	2,239,407	52.37%
GA	T	609,908	632,383	3.68%
Military	J	209,756	444,874	112.09%
Military	P	18,395	5,216	-71.64%
Military	T	162,953	315,857	93.83%
Total		**4,628,070**	**5,116,722**	**10.56%**

J – Jet, **P** – Piston, **T** - Turbine

Table 59 summerizes the comparison of unique AEDT equipment by engine type between current study and 2020 airport AERR EI for 2019 EI.

Table 59: Comparison of AEDT Equipment by Engine Type for 2019 EI

	Engine type	Unique AEDT equipment	Shared	Percentage	Not shared	Percentage
Current Project	J	227	102	44.93%	125	55.07%
	P	107	88	82.24%	19	17.76%
	T	110	42	38.18%	68	61.82%
2020 Airport AERR EI	J	252	102	40.48%	150	59.52%
	P	96	88	91.67%	8	8.33%
	T	79	42	53.16%	37	46.84%

Shared - AEDT equipment are used in both studies; **Not shared** - AEDT equipment are only used in one study

Figure 14 presents the scattered plot of LTOs and pollutants by landing facilities in facility groups commercial and reliever. Except for Pb emissions, the estimates of pollutants are relatively close. The estimate of Pb emissions in the current study tends to be higher as the number of LTOs of piston-engine aircraft in the current study is higher (shown in Table 58.)

Figure 15 shows the plots for landing facilities in the other groups. Some significant differences can be observed in the estimates of pollutants between the two studies. This is partially due to the difference in the estimates of LTOs.

Table 60 summarizes the 2019 EI of 7 pollutants by SCC. The 2019 EI developed as part of the previous 2020 Airport AERR EI study are presented in Table 61. The difference between the two EIs are shown in Table 62.

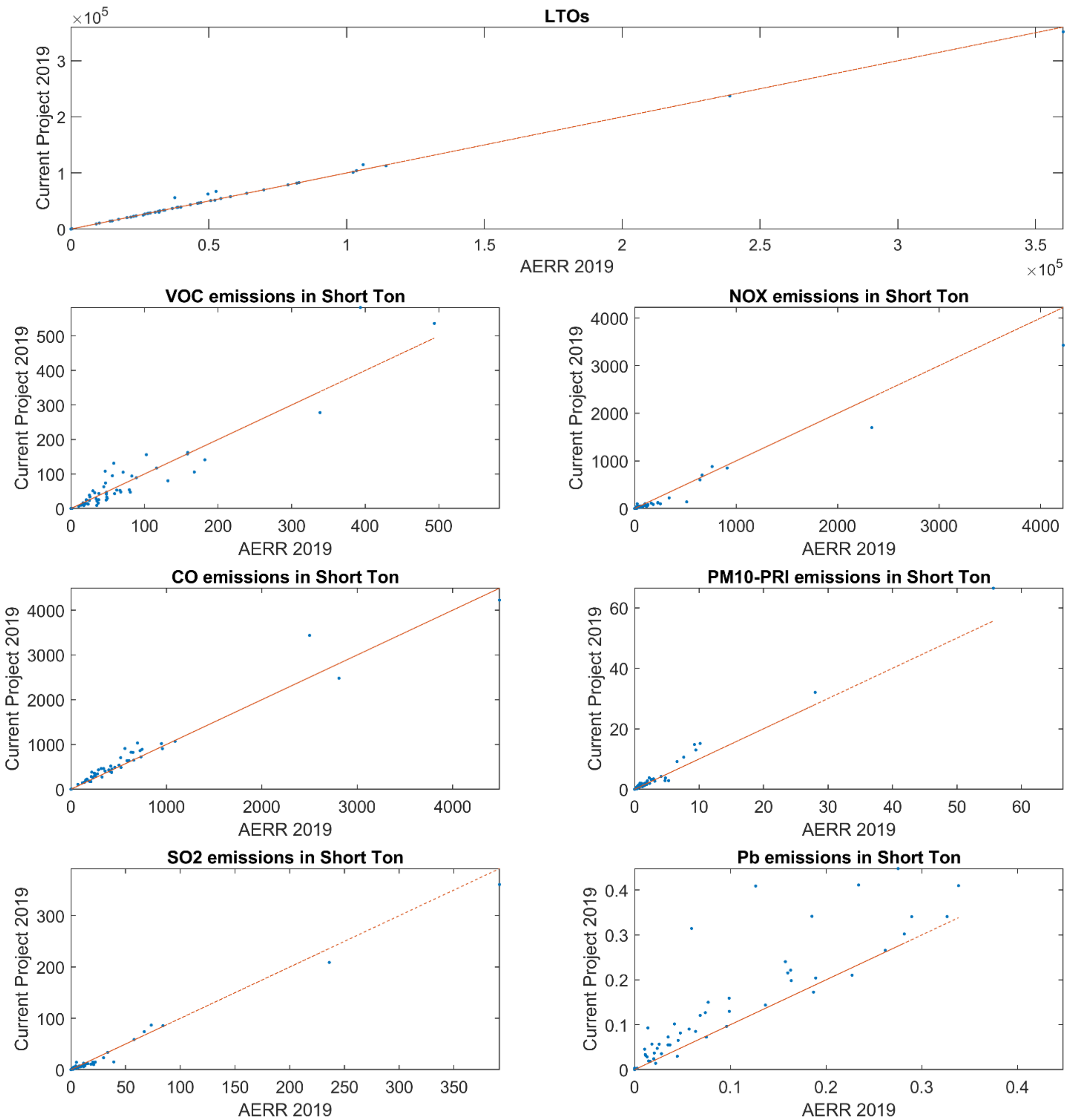

Figure 14: Comparison of 2019 LTOs, and EI of pollutants at commercial and reliever landing facilities

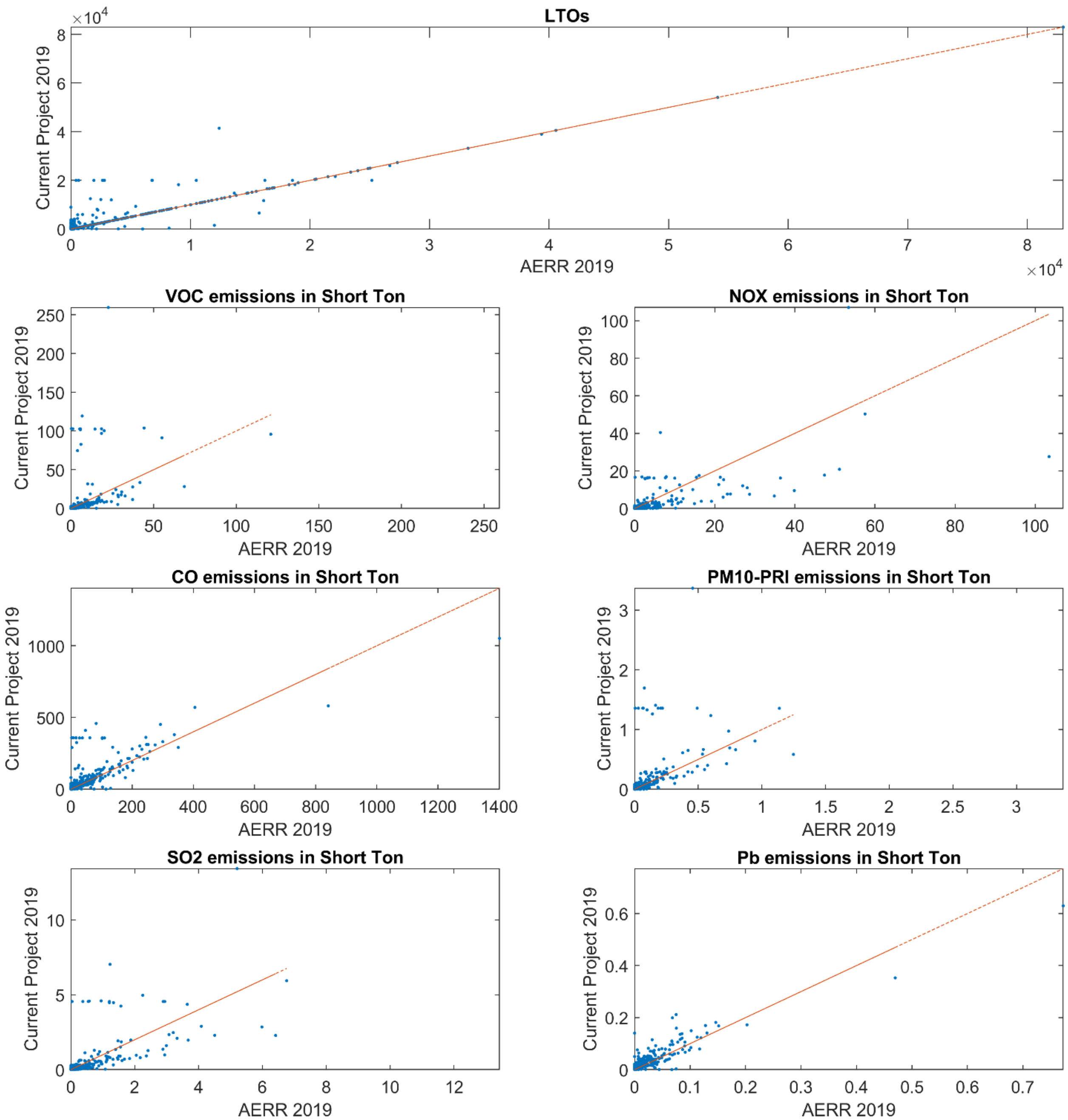

Figure 15: Comparison of 2019 LTOs, and EI of pollutants at other landing facilities.

Table 60: 2019 Annual EI (in short ton) by SCC in the Current Study

SCC Description	VOC	NO_X	CO	PM_{10}-PRI	$PM_{2.5}$-PRI	SO_2	Pb
Commercial Aviation	1,014.685	7,347.75	6,886.05	107.373	107.373	771.571	0.004
Air Taxi: Piston	0.319	0.019	31.701	0.006	0.006	0.029	0.016
Air Taxi: Turbine	264.484	1,466.35	1,397.74	26.432	26.432	154.035	-
GA: Piston	489.167	44.949	33,015.10	23.228	23.228	39.507	19.468
GA: Turbine	1,627.110	1,119.73	4,360.77	32.356	32.356	174.941	-
Military	3,549.102	523.548	12,421.79	39.141	39.141	177.539	0.033
APU	33.116	327.555	619.076	42.233	42.233	54.572	-
GSE: Gasoline-fueled	83.045	177.312	2,996.30	-	-	-	-
GSE: Diesel-fueled	41.046	334.785	90.657	12.904	12.904	-	-
Annual Total	7,102.075	11,341.99	61,819.18	283.673	283.673	1,372.194	19.521
Daily total	19.46	31.07	169.37	0.78	0.78	3.76	0.05

Table 61: 2019 Annual EI (in short ton) by SCC in past study (2020 Airport AERR EI)

SCC Description	VOC	NO_X	CO	PM_{10}-PRI	$PM_{2.5}$-PRI	SO_2	Pb
Commercial Aviation	1,856.767	10,312.15	11,525.60	91.813	91.813	977.821	0.785
Air Taxi: Piston	-	-	-	-	-	-	-
Air Taxi: Turbine	166.543	780.191	561.288	9.663	9.663	60.353	-
GA: Piston	458.676	28.042	23,852.31	12.791	12.791	24.538	13.826
GA: Turbine	2,307.866	2,094.93	6,444.30	38.950	38.950	253.256	-
Military	894.028	623.825	4,988.94	11.639	11.639	102.345	0.124
APU	34.523	390.315	594.817	51.491	51.491	65.343	-
GSE: Gasoline-fueled	87.126	180.254	3,072.97	-	-	-	-
GSE: Diesel-fueled	26.691	197.211	55.142	5.623	5.623	-	-
Annual Total	5,832.221	14,606.92	51,095.37	221.970	221.970	1,483.656	14.735
Daily total	15.98	40.02	139.99	0.61	0.61	4.06	0.04

Table 62: 2019 EI Difference by SCC between Current Study and past study (2020 Airport AERR EI)

SCC Description	VOC	NO_X	CO	PM_{10}-PRI	$PM_{2.5}$-PRI	SO_2	Pb
Commercial Aviation	-45.35%	-28.75%	-40.25%	16.95%	16.95%	-21.09%	-99.49%
Air Taxi: Piston	-	-	-	-	-	-	-
Air Taxi: Turbine	58.81%	87.95%	149.02%	173.52%	173.52%	155.22%	-
GA: Piston	6.65%	60.29%	38.41%	81.61%	81.61%	61.01%	40.81%
GA: Turbine	-29.50%	-46.55%	-32.33%	-16.93%	-16.93%	-30.92%	-
Military	296.98%	-16.07%	148.99%	236.30%	236.30%	73.47%	-73.38%
APU	-4.08%	-16.08%	4.08%	-17.98%	-17.98%	-16.48%	-
GSE: Gasoline-fueled	-4.68%	-1.63%	-2.49%	-	-	-	-
GSE: Diesel-fueled	53.78%	69.76%	64.41%	129.48%	129.48%	-	-
Total	21.77%	-22.35%	20.99%	27.80%	27.80%	-7.51%	32.48%

The comparison of the EI by SCC has mixed results. For example, the EI of the Air Taxi Turbine and GA piston in the current study are higher while the EI of the GA Turbine is lower for all pollutants. The mixed results can be partially explained by the difference in LTOs by SCC. As shown in Table 58, the numbers of LTOs by Air Taxi Turbine and GA piston in the current study are significantly higher than those in the previous study 2020 Airport AERR EI, which leads to higher emissions for all pollutants by the two SCCs. Similarly, the number of LTOs of GA Turbine is significantly lower than the number in the previous study 2020 Airport AERR EI, which results in lower emissions for all pollutants by the SCC. Another factor that contributes to the mixed results is the difference in the estimates of the fleet mix. As shown in Table 59, there are differences in the fleet mix between the two studies. For example, more than 50% of the AEDT equipment by Jet and Turboprop engine aircraft used in the current study is not used in the 2020 airport AERR EI. Similarly, about 50% of the AEDT equipment by Jet and Turboprop engine aircraft used in the 2020 airport AERR EI are not used in the current study. For many of the AEDT equipment used in both studies, their corresponding LTOs in each study are different. The impact of this factor will be further explored in the following section by using the EI provided by airports in the HAS.

The total 2019 EI calculated in the current study has about 22% more VOC, 21% more CO, 27% more PM, 33% more Pb, 22% less NO_x, and 8% less SO_2. As pointed out earlier in the report, airport emissions account for a relatively small portion of the mobile source emissions and then these changes are not expected to result in significant changes in the total mobile source emissions.

The corresponding comparisons for 2020 EI are given in Appendix H.

6.2 Comparison of Results at Airports that Provided their Emissions Estimates

In the previous study 2020 Airport AERR EI, the TTI team received the results of the operational EIs prepared by Crawford Murphy & Tilly, Inc. (CMT) for the three airports in the HAS study (Parise & Pringle, 2021). This section compares the current study 2019 LTOs, fleet mix, and emissions estimates of NO_x in this task with those in the HAS study.

Table 63 compares the key input variables for the AEDT for the two studies. The main differences are the LTOs and fleet mix. The LTOs in the HAS study are from the airports' data. The fleet mixes used to develop the HAS EI for the commercial AC user class are from the airports' monitoring system data and airlines' fleet data. The fleet mixes of other user classes are derived from the previous year's EI or using the highest emitting engines. In contrast, the LTOs in this task are directly from FAA's TAF, whose activity data are collected from airports. To develop the fleet mix of commercial ACs at the three airports, the operation data from FAA's ASQP, TAF, and TFMSC data at each airport are used together with FAA's aircraft registration data. For other user classes, FAA's TFMS data at each airport and FAA's aircraft registration data are used. For an airframe whose engine assignment cannot be determined using the above data, the engine that has the worst overall emission rate is assigned to the airframe.

Table 63: Comparison of the Key Assumptions between the Studies

Variables	HAS study	This task
Airports	IAH, HOU, and EFD	
LTOs	Total annual aircraft activity levels for the three airports were derived using data from the Airport's Statistical Summary Reports.	FAA's TAF (see Chapter 3)
Fleet mix	The aircraft fleet mixes (i.e., aircraft airframe and engine types) were developed using HAS' Airport Noise and Operations Monitoring System (ANOMS) data. For commercial passenger air carriers, the combination of airline, airframe, and engine types operating at the three airports was derived using the 2018 edition of the Turbine-Engine Fleets of the World's Airlines listing by Eastman Chemical Company. If an airline's aircraft type was found to have more than one engine type match in the Eastman document, then the most prevalent engine type was used. For the other categories of the aircraft fleet (i.e., air taxi, GA, and military), the aircraft/engine assignments were based on prior years' inventory data, or the highest emitting engines provided in the FAA's AEDT databases.	The fleet mixes are developed based on FAA's databases. For commercial air carriers at the three airports, the operation data from FAA's ASQP, TAF, and TFMS data at each airport are used together with FAA's aircraft registration data to estimate the fleet mix. For other user classes at the three airports, FAA's TFMS data at each airport and FAA's aircraft registration data are used to estimate the fleet mix. The aircraft airframe/engine assignments are based on FAA's registration data. For an airframe whose engine assignment cannot be determined using FAA's registration data, the engine whose overall emission rate is the worst is assigned to the airframe (see Chapter 3).
APU & GSE	AEDT defaults	AEDT defaults
Taxi times	ASPM	ASPM
Runway	No details are offered in the report	Longest runway
Track	Default track	Default track
Profile	Profiles with the longest stage length	Profiles with the longest stage length

A summary of the statistics of LTOs and NO_x emissions by engine type at the three airports is presented in Table 64. Compared with the HAS study, the number of LTOs by jet-engine aircraft in this task is only 0.5% lower for the IAH airport and 2.27% lower for the HOU airport. However, the corresponding NO_x emissions in this task are 30% lower for the IAH airport and 3.8% higher for the HOU airport. Similarly, the number of LTOs by piston-engine aircraft in this task is only 0.3% lower than in the HAS study; however, the corresponding NO_x emissions in this task is 47.3% higher.

Table 64: Summary Statistics of LTOs and NO_x Emissions (in short tons) by Engine Type between Two EI Studies for Three Houston Airports

Engine Type	LTO	LTO percentage	NO_x	NO_x percentage	NO_x/LTO
IAH current study					
Jet engine (J)	236,334	99.69%	1,658.10	99.98%	7.02E-03
Piston engine (P)	223	0.09%	0.00	0.00%	1.05E-05
Turboprop engine (T)	520	0.22%	0.27	0.02%	5.24E-04
Total	237,078	100.00%	1,658.37	100.00%	7.00E-03
IAH HAS study					
J	237,516	99.368%	2,393.44	99.98%	1.01E-02
P	205	0.086%	0.00	0.00%	7.85E-06
T	1,306	0.546%	0.55	0.02%	4.25E-04
Total	239,027	100.00%	2,394.00	100.00%	1.00E-02
HOU current study					
J	93,995	92.87%	689.57	99.59%	7.34E-03
P	1,454	1.44%	0.03	0.00%	1.77E-05
T	5,766	5.70%	2.78	0.40%	4.82E-04
Total	101,216	100.00%	692.38	100.00%	6.84E-03
HOU HAS study					
J	96,182	94.12%	664.36	99.70%	6.91E-03
P	1,473	1.44%	0.01	0.00%	6.27E-06
T	4,539	4.44%	1.98	0.30%	4.35E-04
Total	102,194	100.00%	666.34	100.00%	6.52E-03
EFD current study					
J	29,185	52.19%	94.08	95.05%	3.22E-03
P	17,480	31.26%	0.28	0.28%	1.59E-05
T	9,260	16.56%	4.62	4.67%	4.99E-04
Total	55,925	100.00%	98.98	100.00%	1.77E-03
EFD HAS study					
J	14,592	39.23%	23.71	90.86%	1.62E-03
P	17,533	47.14%	0.19	0.71%	1.06E-05
T	5,072	13.64%	2.20	8.43%	4.34E-04
Total	37,197	100.00%	26.10	100.00%	7.02E-04

Since more than 90% of the LTOs at the IAH and HOU airports in HAS study can be attributed to jet-engine aircraft, the TTI team further compared the emissions of NO_x by individual AEDT jet-engine equipment at the two airports between the two studies. The comparisons of the top 20 AEDT equipment in terms of LTOs for the two airports are presented in Table 65 and Table 66, respectively. For the IAH airport, 10 of the 20 AEDT equipment in the HAS study are included in this task (the equipment with the value

“TRUE” in column “Equip In CS”) and their NO_x emissions per LTO (columns “NO_x/LTO” and “NO_x/LT In CS”) are close between the two studies with the difference (column “Percentage difference”) being less than 1%. Similarly, for the HOU airport, eight of the 20 AEDT equipment in the HAS study are also included in this task and the difference in their NO_x emissions per LTO between the two studies is also less than 1%. These comparisons show that the estimates of NO_x emissions for the same AEDT equipment are almost the same in the two studies. As a result, the considerable difference in the NO_x emissions estimates for the two airports between this task and the HAS study was mainly caused by the difference in the estimates of the types of AEDT equipment and their LTOs (i.e., the fleet mix).

Table 65: Results for the Top 20 AEDT Equipment for the IAH Airport

Airframe Model	Engine Code	Engine Type	LTO	LTO Percentage	NO_x	NOx Percentage	NO_x/LTO	Airframe In current study	Equip In current study	NO_x/LT In current study	Percentage difference
Embraer ERJ175-LR	01P08GE198	J	51,994	21.75%	192.90	8.06%	3.71E-03	FALSE	FALSE		
Embraer ERJ145	6AL015	J	25,339	10.60%	129.23	5.40%	5.10E-03	TRUE	FALSE		
Boeing 737-900 Series	3CM032	J	23,426	9.80%	267.99	11.19%	1.14E-02	TRUE	TRUE	0.01138	-0.52%
Boeing 737-800 Series	8CM051	J	19,035	7.96%	240.22	10.03%	1.26E-02	TRUE	TRUE	0.01255	-0.55%
Airbus A320-200 Series	1IA003	J	17,778	7.44%	243.38	10.17%	1.37E-02	TRUE	TRUE	0.01369	0.00%
Embraer ERJ145	01P06AL032	J	11,705	4.90%	49.98	2.09%	4.27E-03	TRUE	FALSE		
Airbus A319-100 Series	V2522D	J	10,411	4.36%	126.81	5.30%	1.22E-02	TRUE	FALSE		
Boeing 737-700 Series	3CM030	J	8,589	3.59%	74.72	3.12%	8.70E-03	TRUE	TRUE	0.00866	-0.46%
Embraer ERJ170	01P08GE197	J	7,708	3.22%	27.98	1.17%	3.63E-03	TRUE	TRUE	0.00362	-0.28%
Bombardier CRJ-200	01P05GE189	J	4,946	2.07%	8.51	0.36%	1.72E-03	FALSE	FALSE		
Boeing 737-800 Series	3CM034	J	4,433	1.85%	58.74	2.45%	1.33E-02	TRUE	TRUE	0.01315	-0.75%
Bombardier CRJ-700	5GE083	J	4,251	1.78%	20.19	0.84%	4.75E-03	TRUE	FALSE		
Boeing 767-300 Series	10PW098	J	3,817	1.60%	121.84	5.09%	3.19E-02	TRUE	FALSE		
Airbus A320-100 Series	1IA003	J	3,764	1.57%	50.48	2.11%	1.34E-02	FALSE	FALSE		
Boeing 767-300 Series	01P02GE188	J	2,875	1.20%	71.90	3.00%	2.50E-02	TRUE	FALSE		
Boeing 767-300 Series	1PW043	J	2,595	1.09%	73.41	3.07%	2.83E-02	TRUE	TRUE	0.02819	-0.35%
Bombardier CRJ-700	01P08GE190	J	2,457	1.03%	11.40	0.48%	4.64E-03	TRUE	FALSE		
Airbus A319-100 Series	3CM028	J	2,440	1.02%	28.18	1.18%	1.16E-02	TRUE	TRUE	0.0115	-0.43%
Embraer ERJ190	8GE116	J	2,334	0.98%	11.39	0.48%	4.88E-03	TRUE	TRUE	0.00486	-0.41%
Boeing MD-90	1IA004	J	2,095	0.88%	24.93	1.04%	1.19E-02	TRUE	TRUE	0.01185	-0.42%

The data is provided in the HAS study (Parise & Pringle, 2021). Emissions are in short tons.

Table 66: Results for the Top 20 AEDT Equipment for the HOU Airport

Airframe Model	Engine Code	Engine Type	LTO	LTO Percentage	NO_x	NO_x Percentage	NO_x/LTO	Airframe In current study	Equip In current study	NO_x/LT In current study	Percentage difference
Boeing 737-700 Series	3CM032	J	47135	46.05%	439.77	65.99%	0.00933	TRUE	TRUE	0.00931	-0.21%
SMR100	01P11CM112	J	17010	16.62%	125.19	18.79%	0.00736	FALSE	FALSE		
Cessna 560 Citation XLS	PW530	J	2601	2.54%	2.57	0.39%	0.00099	TRUE	TRUE	0.00099	0.00%
Bombardier CRJ-900	01P08GE190	J	2243	2.19%	9.44	1.42%	0.00421	FALSE	FALSE		
Embraer 505	PW530	J	2067	2.02%	1.05	0.16%	0.00051	FALSE	FALSE		
Boeing 717-200 Series	4BR004	J	1838	1.80%	13.33	2.00%	0.00725	TRUE	TRUE	0.00724	-0.14%
Raytheon Hawker 800	1AS002	J	1734	1.69%	3.52	0.53%	0.00203	FALSE	FALSE		
Raytheon Super King Air 200	PT67B	T	1345	1.31%	0.62	0.09%	0.00046	TRUE	FALSE		
Raytheon Super King Air 300	P660AG	T	1270	1.24%	0.70	0.10%	0.00055	TRUE	FALSE		
Cessna 680 Citation Sovereign	14PW103	J	1260	1.23%	2.57	0.39%	0.00204	TRUE	TRUE	0.00204	0.00%
Gulfstream IV-SP	1RR019	J	1248	1.22%	6.31	0.95%	0.00506	FALSE	FALSE		
Bombardier Learjet 45	1AS001	J	1146	1.12%	1.26	0.19%	0.0011	FALSE	FALSE		
Bombardier Challenger 600	1GE034	J	1134	1.11%	1.54	0.23%	0.00136	TRUE	TRUE	0.00136	0.00%
Bombardier Challenger 300	11HN003	J	1060	1.04%	2.34	0.35%	0.00221	TRUE	TRUE	0.00221	0.00%
Dassault Falcon 2000	CF700D	J	1039	1.02%	0.84	0.13%	0.00081	FALSE	FALSE		
Pilatus PC-12	PT67B	T	1011	0.99%	0.36	0.05%	0.00036	TRUE	TRUE	0.00036	0.00%
Cessna Citation Hemisphere	BIZMEDIUMJET_F	J	934	0.91%	1.85	0.28%	0.00198	FALSE	FALSE		
Cessna 525 CitationJet	1PW035	J	826	0.81%	0.44	0.07%	0.00053	TRUE	TRUE	0.00053	0.00%
Cessna 750 Citation X	01P07PW145	J	786	0.77%	2.26	0.34%	0.00288	TRUE	FALSE		
Gulfstream V-SP	8RR043	J	734	0.72%	1.78	0.27%	0.00242	FALSE	FALSE		

The data is provided in the HAS study (Parise & Pringle, 2021). Emissions are in short tons.

7 CONCLUSIONS

This chapter summarizes the TTI study team's major accomplishments under this project and provides recommendations for possible future work.

7.1 Major Accomplishments

TTI study team developed updated methodologies and procedures to estimate aircraft activity (i.e., LTOs and fleet mix) for all landing facilities in Texas using the regularly-collected FAA data sets, which are free to the general public.

The TTI study team compared this project's 2019 aircraft activity estimates to those from the previous study 2020 Airport AERR EI. The major conclusions are as follows:

1. The total estimated 2019 LTOs in the current study are 10% higher than those in the previous study 2020 Airport AERR EI. Compared to the previous study's LTOs, the current study's LTOs are 0.3% lower for commercial airports and 4% higher for relievers. The TTI study team concluded that a major reason behind the difference in LTOs was a difference in the methodologies used to generate these estimates.
    a. In the previous study, one of the data sources used to develop the commercial and reliever LTOs was from surveying airport staff.
    b. In contrast, the commercial and reliever LTOs in the current study were estimated from the TAF. Since these commercial and reliever airports are all towered airports, their flight operation data are usually collected by their air traffic control staff.
2. The AC user class's LTOs percentage in the current study is half the previous study's whereas the LTOs percentage in the other user classes is higher in the current study. The TTI study team determined that the differences in LTO percentages were mainly the result of differences in data input.
    a. In the previous study, LTOs by user class were estimated using TFMSC data, which contained few local GA and AT flights. Using the TFMSC data resulted in an overestimation of LTOs by the AC user class and an underestimate of the LTO percentages in the other user classes.

   b. In contrast, the current study estimated LTOs by user class using data collected from the landing facilities (i.e., the TAF and AMR), which has less bias against local flights compared to the TFMSC data.

3. The current study's total market share for aircraft with jet engines is 10% lower compared to the previous study 2020 Airport AERR EI whereas the total market share for aircraft with piston engines is 10% higher.

   a. The previous study used TFMSC data to estimate the fleet mix for each combination of itinerant and local LTOs. However, since TFMSC data contained few local GA and AT flights, the TTI study team suspects using TFMSC data may have resulted in an underestimation of LTOs by aircraft with piston engines.

   b. In contrast, this current study estimates the fleet mix for itinerant and local LTO separately, where most of the latter was performed by aircraft with piston engines.

The TTI study team automated the process of converting the aircraft activity and other inputs into the ASIFs for AEDT to calculate emissions. The TTI study team assessed the impact of the aircraft activity estimated in this study on the EI by conducting a sensitivity analysis and comparing the EI calculated in this study with those reported in other studies.

- For the sensitivity analysis, the TTI study team found that engine models, profile stage length, and taxi-out and taxi-in times could have a significant impact on the emissions estimates. APU usage time and runway length could have a minor or low impact on the emissions estimates.
- By comparing the NO_x emissions calculated in this project for the airports in the HAS with those reported in the HAS study, the TTI study team found that the fleet mix data used could have a significant impact on the emissions estimates.
- Compared with those published in the 2020 Airport AERR EI, partially due to the higher estimate of LTOs, this project estimated higher volatile organic compounds (VOC), carbon monoxide (CO), particulate matter (PM, under 10 microns and 2.5 microns), and lead (Pb). Because of the difference in the estimates of the fleet mix, conversely, nitrogen oxides (NO_X), sulfur dioxide (SO_2), and carbon dioxide (CO_2) emissions in the 2020 Airport AERR EI were higher compared to those estimated in this project.

As indicated in this study, aircraft activity data can have a significant impact on EI development and the accuracy of emissions estimates. The TTI study team recommends that:

1. A continuous effort should be made to improve the estimates of aircraft activity and other inputs to which the EI is sensitive. Since the airport EI could change significantly as changes to these inputs are made, improvements should be made as early as possible to reduce their impact on the EI calculation.
2. As landing facilities are the best sources to obtain accurate activity data and fleet mix, the TTI study team will continue to work closely with landing facilities, especially the commercial and reliever airports, to generate accurate activity data and fleet mix for future EI development. However, the updated methodologies and procedures to estimate aircraft activity, including the resulting activity data sets, developed in this project be used for scenarios where landing facilities cannot provide such data.

7.2 Future Work

For future studies, the TTI study team recommends the following:

1. Continue to explore the possibility of using additional data sources from emerging technologies (e.g., ADS-B data) to estimate and validate aircraft activity as such data sources expand and become more robust. In addition, if the project budget permits, data from third-party data vendors such as FlightAware and flightradar24 can be purchased and evaluated.

2. Continue to assess and improve the methodologies and assumptions employed to develop aircraft activity. In particular, the further effort could be devoted to improving the methods and assumptions for assigning aircraft engines to airframes with multiple engine options.

3. Develop an online dashboard to disseminate important activity data and AEDT inputs used to develop EIs to landing facilities and gather their input and feedback.

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APPENDIX A: ESTIMATES OF LTOS FOR TEXAS LANDING FACILITIES (ELECTRONIC ONLY)

Available from the TCEQ upon request.

APPENDIX B: FAA REGISTRATION RECORDS WITH ASSIGNED AEDT EQUIPMENT AND TFMSC AIRCRAFT TYPE MAPPED TO AEDT AIRFRAME (ELECTRONIC ONLY)

Available from the TCEQ upon request.

APPENDIX C: FREQUENCY OF AEDT EQUIPMENT IN FAA REGISTRATION DATA (ELECTRONIC ONLY)

Available from the TCEQ upon request.

APPENDIX D: FLEET MIX OF LTOS FOR TEXAS LANDING FACILITIES (ELECTRONIC ONLY)

Available from the TCEQ upon request.

APPENDIX E: TAXI-IN AND TAXI-OUT TIMES (ELECTRONIC ONLY)

Available from the TCEQ upon request.

APPENDIX F: AFIS XML INPUT FILE CREATION

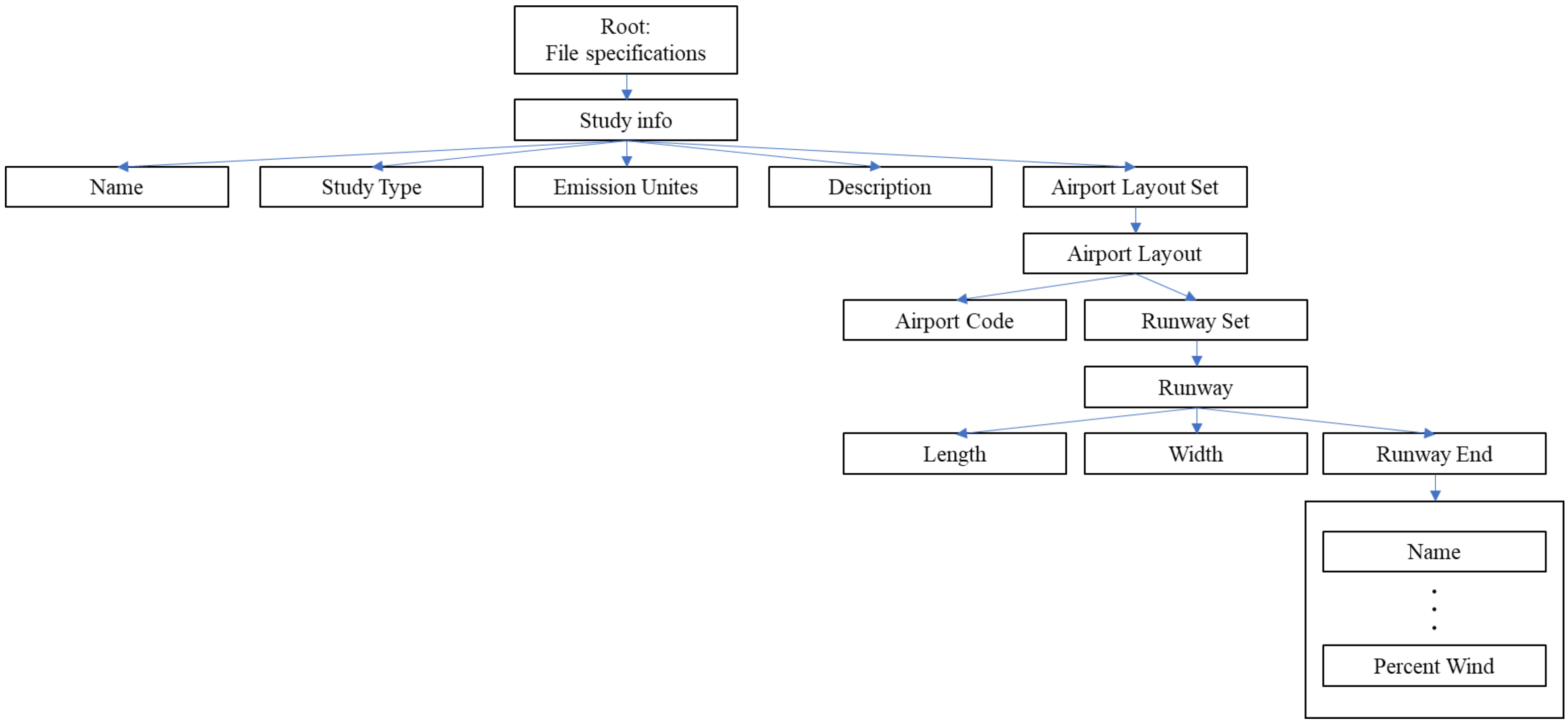
THE AFIS XML INPUT FILE

The AFIS input file is an XML file format that is text-based. The data values in the AFIS file can be imported from the airport runway data and LTOs data. There are mainly two parts in the input XML file, which are: the airport runway information, and the test case information. The target XML file can be created by Python *etree.cElementTree* package. The main input files include:

1. The airport runway data, including detailed information on the airport runways.
2. The LTOs data, including detailed information on the airport operation.

METHODOLOGY

The methodology behind the XML file creation is to generate a tree-structured data entry that includes various tags and values. The tree should have a root and sub-elements, each of the sub-elements may have numerous child elements. The child elements need to be generated by specifying their parent elements. The runway part of the tree for the AFIS input file (Figure below) is designed as follows:



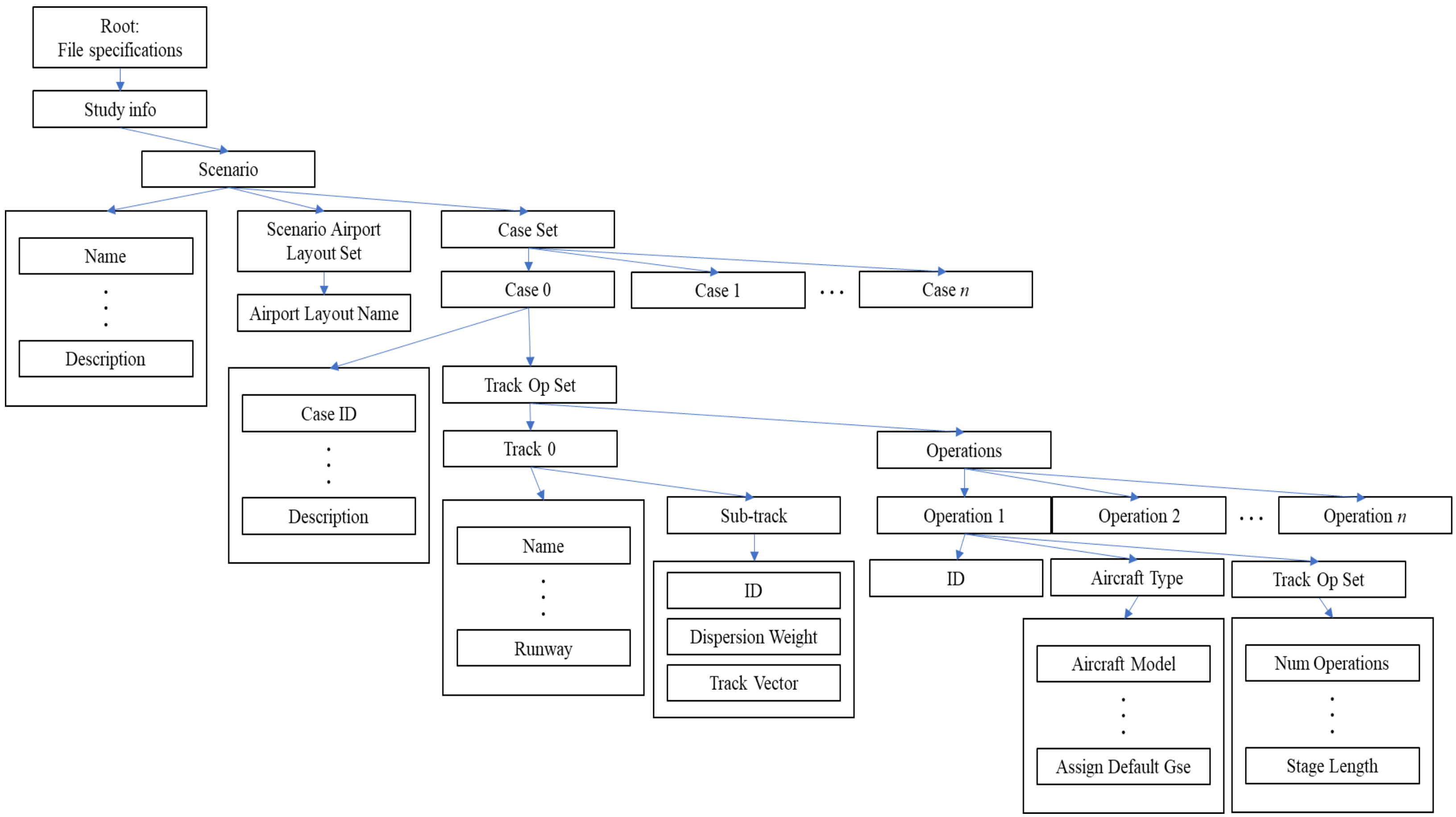
Structure for the Runway Part of the Tree for the AFIS Input File

In this part, several elements are constant such as study info, name, study type, *etc*. Other variables can be achieved from the airport runway file by the following mappings:

1. Variable "*airportcode*" from airport runway file entry "APT_AEDT_CODE"
2. Variable "*length*" from airport runway file entry "LENGTH"
3. Variable "*width*" from airport runway file entry "WIDTH"
4. Variable "*name*" from airport runway file entry "RunwayEndID1/2_NAME"
5. Variable "*latitude*" from airport runway file entry "RunwayEnd1/2_LAT"
6. Variable "*longitude*" from airport runway file entry "RunwayEnd1/2_LON"
7. Variable "*elevation*" from airport runway file entry "RunwayEnd1/2_ELEV"
8. Variable "*threshCrossHeight*" from airport runway file entry "RunwayEnd1/2_CRS_HGT"
9. Variable "*glideSlope*" from airport runway file entry "RunwayEnd1/2_GLD_SLP"
10. Variable "*depDispThresh*" from airport runway file entry "RunwayEnd1/2_DSP_THR_TKO"
11. Variable "*appDispThresh*" from airport runway file entry "RunwayEnd1/2_DSP_THR_APP"
12. Variable "*percentWind*" from airport runway file entry "RunwayEnd1/2_PCT_WIND"

The second part of the XML file tree is the scenario information as shown in Figure 2B. The main variables can be achieved from the airport runway file and LTOs file by the following mappings:

1. Variable "*runway*" from the airport runway file select the longest runway
2. Variable "*airframeModel*" from LTOs file entry "AEDT_Airframe_Model"
3. Variable "*engineCode*" from LTOs file entry "AEDT_Engine_Code"
4. Variable "*engineModCode*" from LTOs file entry "ENGINE_MOD_CODE"
5. Variable "*apuName*" from LTOs file entry "APU_NAME"
6. Variable "*flightNumber*" from LTOs file entry "EQUIP_ID", "Mode"
7. Variable "*userType*" from LTOs file entry "Mode", "AEDT_Engine_Type"
8. Variable "*userParam*" from LTOs file entry "F" for fixed wing, "R" for rotating wing
9. Variable "*saeProfile*" from LTOs file entry "D_Profile_Name"
10. Variable "*stageLength*" from LTOs file entry "D_Profile_StageLength"



Structure for the "Width" Variable

Special Notes

Each record in the LTOs file doubles as one departure case and one arrival case, For most of the entries, these cases are the same, however, there are specific scenarios where this is different. For example, the variable "*saeProfile*" for departure cases are read from the entry "D_Profile_Name" in the LTOs file, while for arrival cases, it should read from the entry "A_Profile_Name".

Another thing that needs to be mentioned is the fixed-wing plane and helicopter operations. For fixed-wing plane operations, the track needs to be selected, and some variable such as "*userParam*" needs to be set as "F". For helicopter operations, the track should be the helicopter pad and the variable "*userParam*" should be assigned "R" for rotating-wing. As for the test code that creates the XML files through Python, some variables are set as constants, such as "distance" and some of the scenario information.

APPENDIX G: ASIFS BY FACILITY CATEGORY (ELECTRONIC ONLY)

Available from the TCEQ upon request.

APPENDIX H: 2020 ANNUAL EI AND COMPARISON WITH THE 2020 AIRPORT AERR EI

Table 67: Comparison of LTOs by User Class and Engine Type for 2020 EI

Mode	Engine Type	LTO (2020 Airport AERR EI)	LTO (current study)	Difference
Commercial Aviation	J	823,766	603,465	-26.74%
Commercial Aviation	P	96,996	335	-99.65%
Commercial Aviation	T	167,304	6,213	-96.29%
Air Taxi	J	83,836	194,748	132.29%
Air Taxi	P	0	1,419	-
Air Taxi	T	12,883	41,587	222.80%
GA	J	609,070	338,008	-44.50%
GA	P	1,467,735	2,239,371	52.57%
GA	T	596,316	629,194	5.51%
Military	J	180,795	424,283	134.68%
Military	P	17,973	3,222	-82.07%
Military	T	154,332	347,838	125.38%
Total		4,211,007	4,829,682	14.69%

Table 68: Comparison of AEDT Equipment in 2020 EI

	Engine type	Unique AEDT equipment	Shared	Percentage	Not shared	Percentage
Current Project	J	205	95	46.34%	110	53.66%
	P	94	78	82.98%	16	17.02%
	T	101	36	35.64%	65	64.36%
2020 Airport AERR EI	J	244	95	38.93%	149	61.07%
	P	96	78	81.25%	18	18.75%
	T	79	36	45.57%	43	54.43%

Table 69: 2020 Annual EI (in short ton) by SCC in Current Study

SCC Description	VOC	NO_X	CO	PM_{10}-PRI	$PM_{2.5}$-PRI	SO_2	Pb
Commercial Aviation	777.134	5,388.310	5,277.094	75.625	75.625	568.621	0.003
Air Taxi: Piston	0.493	0.027	52.460	0.006	0.006	0.048	0.026
Air Taxi: Turbine	218.912	1,614.394	1,199.148	27.773	27.773	151.762	-
GA: Piston	472.748	45.264	32,274.939	22.576	22.576	38.952	19.116
GA: Turbine	1,480.362	1,004.762	3,950.282	29.037	29.037	158.225	-
Military	3,522.524	462.895	12,482.982	38.521	38.521	170.742	0.023
APU	26.097	260.214	496.075	33.720	33.720	43.584	-
GSE: Gasoline-fueled	60.637	125.249	2,224.629	-	-	-	-
GSE: Diesel-fueled	35.980	246.598	71.575	10.336	10.336	-	-
Annual Total	6,594.887	9,147.714	58,029.185	237.592	237.592	1,131.932	19.168
Daily total	18.07	25.06	158.98	0.65	0.65	3.10	0.05

Table 70: 2020 Annual EI (in short ton) by SCC in past study (2020 Airport AERR EI)

SCC Description	VOC	NO_X	CO	PM_{10}-PRI	$PM_{2.5}$-PRI	SO_2	Pb
Commercial Aviation	1,442.721	7,272.281	8,682.065	65.525	65.525	689.204	0.776
Air Taxi: Piston	-	-	-	-	-	-	-
Air Taxi: Turbine	148.814	716.969	490.560	8.904	8.904	54.073	-
GA: Piston	456.998	27.943	23,751.620	12.701	12.701	24.395	13.774
GA: Turbine	2,171.014	1,872.747	6,030.658	35.375	35.375	230.189	-
Military	788.673	511.481	4,466.014	10.113	10.113	87.344	0.121
APU	25.780	282.721	470.420	38.084	38.084	48.122	-
GSE: Gasoline-fueled	63.753	135.133	2,292.949	-	-	-	-
GSE: Diesel-fueled	20.668	150.579	41.618	4.352	4.352	-	-
Annual Total	5,118.422	10,969.854	46,225.903	175.053	175.053	1,133.327	14.670
Daily total	14.02	30.05	126.65	0.48	0.48	3.11	0.04

Table 71: 2020 EI difference by SCC between Current Study and past study (2020 Airport AERR EI)

SCC Description	VOC	NO_X	CO	PM_{10}-PRI	$PM_{2.5}$-PRI	SO_2	Pb
Commercial Aviation	-46.13%	-25.91%	-39.22%	15.41%	15.41%	-17.50%	-99.61%
Air Taxi: Piston	-	-	-	-	-	-	-
Air Taxi: Turbine	47.10%	125.17%	144.44%	211.92%	211.92%	180.66%	-
GA: Piston	3.45%	61.99%	35.89%	77.75%	77.75%	59.67%	38.78%
GA: Turbine	-31.81%	-46.35%	-34.50%	-17.92%	-17.92%	-31.26%	-
Military	346.64%	-9.50%	179.51%	280.91%	280.91%	95.48%	-80.65%
APU	1.23%	-7.96%	5.45%	-11.46%	-11.46%	-9.43%	-
GSE: Gasoline-fueled	-4.89%	-7.31%	-2.98%	-	-	-	-
GSE: Diesel-fueled	74.09%	63.77%	71.98%	137.51%	137.51%	-	-
Total	28.85%	-16.61%	25.53%	35.73%	35.73%	-0.12%	30.66%

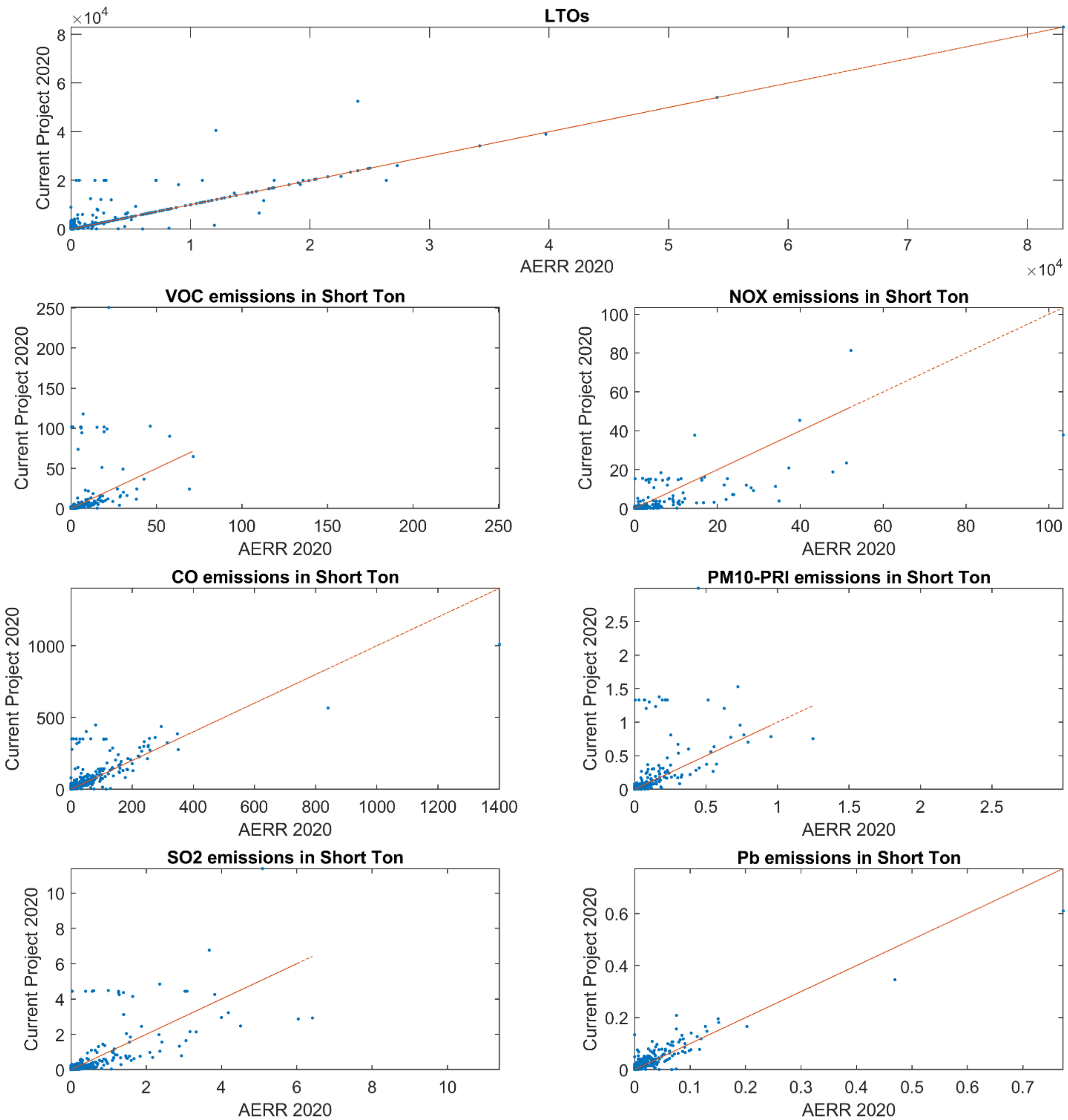


Figure 16: Comparison of 2020 LTOs, and EI of pollutants at commercial and reliever landing facilities

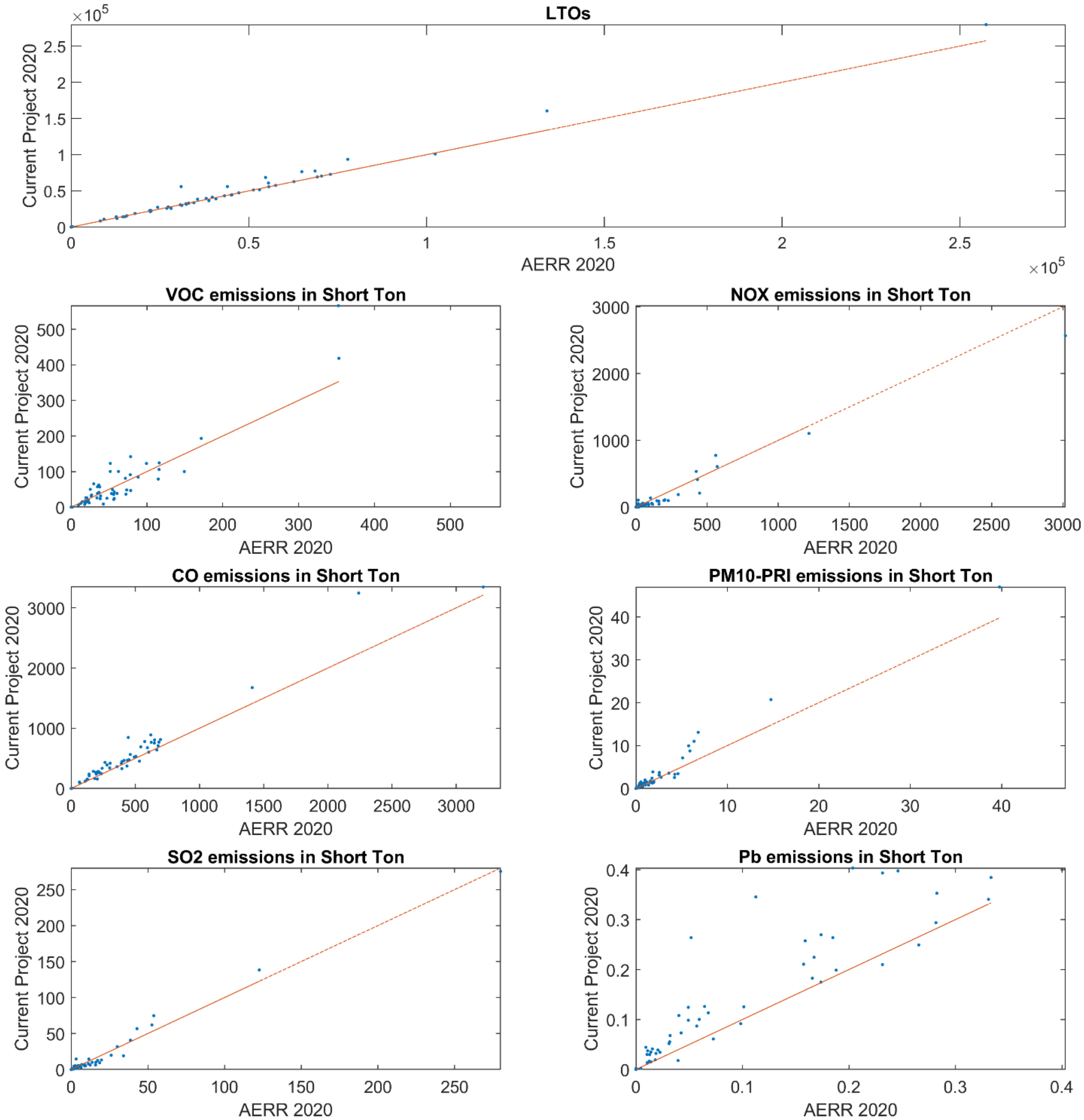


Figure 17: Comparison of 2020 LTOs, and EI of pollutants at other landing facilities